Centre for Aerospace & Defence Laws (CADL)
Directorate of Distance Education
NALSAR University of Law, Hyderabad

Course Material

P.G. DIPLOMA (GIS & REMOTE SENSING LAWS)

1.1.3. GIS Technology and Law

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(For private circulation only)

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MODULE-I

INTRODUCTION TO GIS

MODULE-I: INTRODUCTION TO GIS

Introduction: Most of the information that concerns our surroundings is called spatial data relating to the surface of the Earth. From the beginning of his existence, the man collected them and made their analysis, enabling the public to specify the conclusions about their surroundings. Over time, the analysis became increasingly complex and included an increasing amount of data. Nowadays, the amount of data is growing dynamically, which makes it impossible to analyse all information. A very good tool for their collection seemed to be various types of IT systems. However, they did not give the opportunity to present in- formation in a spatial way. It was only geographic information systems that allowed man to gather this information, order and store. Data, constantly updated, enabled conducting complex analyses in a shorter time. What once lasted for months can now be done in a few days.

In each of the systems included in the GIS, several characteristic elements can be distinguished. The most important of them are: data, people, hardware, software and data sharing procedures. It should also fulfil appropriate functions, among which one can mention: data collection, their verification and preliminary elaboration, data management, data processing and analysis as well as visualization. The rapid development of information technology has allowed GIS systems to be widely used in many areas of life, including mining.

History of GIS: Before geographic information systems (GIS) were introduced to the world, and to the world of academic geography, place and the uniqueness of place was considered all-important. In the 1950s and early 1960s the uniqueness of place was challenged by the rise of quantitative and theoretical approaches to geography. In the 1960s the rise of geographic information systems gradually led to an ascendancy of a spatial and scientific approach to geography. By the late 1980s, GIS were providing jobs for students who were educated and trained to use and develop these new software tools. However, throughout the decades since GIS were developed there were those in the discipline who celebrated the uniqueness of place and the value of qualitative geography and a plethora of nonquantitative and aspatial approaches to geography. This entry will show how, during the last two decades, GIS have attempted to accommodate and assimilate these approaches and how those working in GIS have come to respect both the uniqueness and similarities of places.

Antecedents to geographic information systems: Historical accounts of the origins of GIS invariably pay tribute to the intellectual debt owed to those who sought to organize, visualize, and interpret spatial data. Commonly these discussions reach back into the distant past, frequently referencing the map overlays of troop movements created by the French cartographer, Berthier, during the Battle of Yorktown in the American War of Independence. Equally ubiquitous are references to the work of Dr John Snow, the British physician who, in 1854, mapped the incidence of cholera in London, thus providing strong evidence that the disease was water- and not air-borne (Waters 1998). Both Berthier and Snow sought to map their data so that it might be used to understand the underlying processes that produced the data and provide operational insights as to how it might be exploited.

Despite these promising beginnings it was not until almost a century later that planners and professional geographers once again began to utilize the mapping of combinations of spatial data in the overlay process that was to become one of the most quintessential of GIS operations. The origins of the overlaying of mapped data in planning are described

by Steinetz, Parker, and Jordan (1976). Their research shows that in the United States the method of overlay analysis was implicit in the work of Warren Manning in his 1912 study of the town of Billerica, MA, work that was subsequently published in the journal Landscape Architecture Quarterly in 1913. Steinetz, Parker, and Jordan also recognized the implied use of overlay analysis in the results of a competition for the design of a new plan for the city of Düsseldorf in Germany that were published in 1912. Steinetz and his colleagues described other studies that used overlay procedures throughout the first half of the twentieth century, but it was not until the work of Jacqueline Tyrwhitt and Jack Whittle appeared in the Town and Country Planning Textbook; An Indispensable Book for Town Planners, Architects, and Students (cited and discussed by Steinetz, Parker, and Jordan 1976) that detailed and explicit accounts of the overlay process and ensuing spatial analysis were explained. The technique was quickly popularized by many others including, most famously, Ian McHarg (1969). Because of the popularity of McHarg′s book, Design with Nature (now cited well over 3000 times in the academic literature), he is regarded as having had a prodigious influence on the development of GIS, but Design with Nature did not provide a description of a methodology for computerizing the overlay process, although such a methodology is indeed articulated in the article by Steinetz, Parker, and Jordan (1976).

It is important to note that before software and hardware systems were developed that were formally recognized as ″geographic information systems" there were numerous developments that occurred within the classified military arena. Clarke and Cloud (2000), for example, have provided a detailed assessment of the importance to the development of the associated field of analytical cartography of the US CORONA program of reconnaissance satellites that was operated by the Central Intelligence Agency from 1959 to 1972 along with the associated SAGE program for processing the imagery.

The era of geographic information systems: In their account of the early history of GIS, published as part of the first major review of the field, Coppock and Rhind (1991) divided their retrospective into four periods: (i) the pioneer period from the mid-1950s to approximately 1975; (ii) the government-supported, experimental period beginning in the mid-1970s and ending in the early 1980s; (iii) the commercial period from the early 1980s to 1990; and (iv) the user dominance era starting in 1990. For all four periods Coppock and Rhind discuss the significance of conceptual developments, progress and improvements in software and hardware, and the contributions of academia, commercial enterprises, and governments. This discussion follows Copock and Rhind′s schema. For an alternative view of the early days of GIS see Foresman (1998). Foresman′s edited book is noteworthy for providing a more operational and raster-oriented coverage of the origins of GIS, and for including many chapters written by the ″pioneers" of GIS. His chronology of the evolution of GIS includes a number of overlapping ″ages": the pioneer age, mid-1950s to the early 1970s; the research and development age, the very early 1970s to the mid-1980s; the implementation and vendor age, the early 1980s to the the mid-1990s; the client applications age, the early 1990s to the early 2000s; the local and global network age, the late 1990s onwards into the 2000s. These developments are then correlated with developments in academic geography, computing, and environmental awareness.

The pioneer period: the mid-1950s to the mid-1970s: Conceptual developments during this period included the overlay or ″layer-cake" model for the organization of geographical data discussed previously and the popularization of the geo- graphical data matrix by Brian Berry. Originally, the data matrix was organized with the columns

representing places and the rows representing their attributes. When Berry′s model was incorporated into early GIS software this arrangement was transposed to make the geographical matrix more compatible with standard database technology. Waters (1998) discusses contributions from the field of operations research, where work on decision support systems by IBM researchers was being incorporated into planning-based software.

During the 1960s the first fully functional vector-based GIS, the Canada Geographic Information System (CGIS), was developed. The CGIS, initially a collaboration between Roger Tomlinson′s company, Spartan Air Services of Ottawa, and the Canadian Government′s Canada Land Inventory, produced a series of innovations, including hardware for laser scanning technology and software for vectorizing the resulting images (Waters 1998) and for storing raster layers efficiently, with such developments as Morton ordering. Because of Roger Tomlinson′s seminal contribution to the origins and development of GIS he has often being credited with being the ″father of GIS”. In these early years, those working in the field of GIS were not simply taking advantage of developments in the field of computer science, as computer science did not offer all that was needed for the development of GIS. As the field matured, GIS would indeed take advantage of computer hardware developments and the move away from mainframe computing. External developments in database technology also proved beneficial to the development of GIS.

During this seminal period the Harvard Laboratory for Computer Graphics and Spatial Analysis, established in 1965 by Howard Fisher, laid the foundations for subsequent developments. Thus, the Harvard Laboratory made major algorithmic contributions and produced widely adopted computer mapping packages, such as SYMAP, CALFORM, SYMVU, GRID, POLYVRT, and ODYSSEY. The first three packages for producing line printer maps and 2-D and 3-D plots, respectively, were adopted throughout North American universities. William Warntz became the Director of the Harvard Laboratory in 1969 and made further conceptual contributions, including a recognition that the critical features of surfaces could be used to produce triangulated irregular network (TIN) models to provide more compact storage of surface features. Associated with the Harvard Laboratory at various times was Jack Dangermond, founder (in 1969) and co-owner of the world′s leading GIS company, Esri, which now produces the industry-dominant ArcGIS software. For a complete history of the early days of the Harvard Laboratory see Chrisman (2006). In the United Kingdom, the experimental cartography unit (ECU) was founded in 1967 by David Bickmore, head of the cartography unit at the Clarendon Press. Like the Harvard Laboratory, the ECU stimulated and championed the possibilities of computer-based mapping, providing the incentive for the British Ordnance Survey to move into automated, computer-based mapping.

In 1970 the US Census Bureau produced the first geocoded census. The topological structure of street segments was coded by identifying the IDs of right and left blocks and ″from” and ″to” nodes. Also recorded, using X,Y coordinates, were the address ranges of street segments. These files were known as DIME (dual independent map encoding) files and were the forerunner of the US Census Bureau′s more sophisticated TIGER (topologically integrated geographic encoding and referencing) files (Mark et al. 1997).

One of the primary ways in which new knowledge about GIS has been disseminated is through the organizations that have catered to academia, government, and industry. The Urban and Regional Information Systems Association (URISA) is one of the oldest such

organizations. URISA held its first conference in 1963 and has continued to hold annual conferences up to the present. Over the decades the proceedings of the URISA annual conferences have been a major source of information concerning new developments in the evolution of GIS.

The government-funded experimental research period: the mid-1970s to the early 1980s: Conceptual and software developments during this period were taking place within academia, government agencies, and industry. For example, algorithms to solve location-allocation problems that had been developed in the mid-1960s were now available in stand-alone programs and were also being integrated into software systems, such as GADS (geodata analysis and software display system) developed by IBM′s research division (Waters 1998). In Europe, government-sponsored research led to the development of the Swedish road data bank and other computerized spatial databases.

Developments in GIS reflected advances in the field of computer science. During this period, mainframe systems had given way to minicomputers based on time sharing and, eventually, to desktop microcomputers, enabling the gradual movement of GIS software to these new computing platforms. One of the most prominent and earliest of the government-supported, main- frame GIS of this period was the Minnesota land management information system (MLMIS). This was a raster-based (as opposed to the vector-based CGIS) resource inventory, where the pixel cells had a resolution of 40 acres. By the end of this period, such mainframe systems were gradually becoming obsolete, due to high maintenance costs, the problem of data currency, access issues, and nonuser-friendly command line interfaces. The introduction of powerful workstations in the early 1980s led to the gradual demise of large mainframe systems.

In 1974 the first Auto-Carto conference was held. These conferences, although not held annually, are still held on a regular basis and are now sponsored by the Cartography and Geographic Information Society. Similarly, in Europe, a series of fourteen EuroCarto meetings were held from 1981 to 1997 (every year except for 1982, 1988, and 1996). In 2015, these conferences re-emerged under the sponsorship of the International Cartographic Association (ICA) as the 1st ICA European Symposium on Cartography (EuroCarto 2015).

The commercial period: the early 1980s to the late 1980s : Tomlinson (1987), writing in the first volume of what was to become a flagship journal of GIS, provided a state-of-the-art review of this newly emerging subdiscipline of geography. He noted that significant progress had been made in adopting GIS software in government and commercial organizations, including in the transport and facility planning and management, cadastral systems, agriculture and the environment, and the forestry and civil engineering sectors. He argued that in the future new innovations would come from academia and from government rather than the commercial sector. This was only to be partially true for, in 1982, Esri released ARC/INFO, the first commercial GIS. ARC/INFO adapted the CGIS model of handling the spatial and attribute data separately. The former used Esri′s topological ARC structure while the latter were stored in the INFO relational database. In 1986, Esri released PC ARC/INFO due to the popularity of the IBM PC desktop computer. By 1988, Esri had become a $40 million a year company with clients in forestry applications and other government departments.

Tomlinson (1987) had been correct in arguing that the expansion of commercial GIS was being curtailed by the lack of educational opportunities to produce personnel who could run and maintain GIS facilities, conduct basic research, stimulate new innovations, and

staff university departments. In 1988, to motivate fundamental research into the development of GIS, the US National Science Foundation (NSF) made a grant to a consortium of universities that included the departments of geography at the University of Santa Barbara (the lead institution where Mike Goodchild was the Executive Director), the State University of New York at Buffalo, and the surveying engineering department at the University of Maine. This consortium is now funded with a grant from the NSF of $5 million annually. In addition to its primary focus on research, which manifested itself in a series of research initiatives, the NCGIA (National Center for Geographic Information and Analysis) also developed a core curriculum in GIS comprised of 75 lectures, grouped into three semesters each of 25 lectures. The lectures were initially written by 35 different authors and contained additional laboratory material. They were remarkably successful and by January 1995 over 1300 copies had been distributed to over 70 countries. Eventually, the original core curriculum was made available in Chinese, French, Hungarian, Japanese, Korean, Polish, Portuguese, and Russian. The core curriculum was intended to provide a core set of knowledge that would allow faculty teaching GIS courses to cover a broad set of topics to students new to the discipline.

In February 1987, the UK′s Economic and Social Research Council established four regional research laboratories (RRLs), in London, Edinburgh, Cardiff, and Newcastle. Their mandate involved four primary functions: data management (the provision of a spatial data archive); software development; spatial analysis; and research training together with professional development. Concurrent with the development of the RRLs, the UK′s Lord Roger Chorley chaired the Committee of Inquiry into the Handling of Geographic Information. The Committee′s Report was made public in 1987 (Waters 1998) and made recommendations (subsequently acted upon) that the British Ordnance Survey, the primary supplier of maps to the British public, should move to a fully digital environment.

The period of user dominance: the end of the 1980s to the mid-1990s: Coppock and Rhind state that during the last of their four periods there was intense competition among GIS software manufacturing companies due to ″user dominance” and an associated thinning out of the market to a small number of major vendors. This competition was fostered by the numerous GIS conferences and by the publication of the annual GIS World Sourcebooks (Waters 1998). These volumes were noteworthy for their annual survey of GIS companies and their software, which included detailed tables assessing the capabilities and attributes of the listed GIS software. This ongoing competition resulted in the emergence of a few dominant companies among the GIS software vendors, including Intergraph and Esri. During this period, vendors moved away from the complexity of command line interfaces to graphical user interfaces (GUIs), once again tracking ongoing developments in computer hardware and commercial operating systems (the so-called WIMP interface of windows, icons, menus, and pointers). It was in 1990 that the US Census Bureau introduced its TIGER file system: this, together with the fact that Census Bureau data was freely available, further boosted the US geodemographics industry. Other countries including Canada and the United Kingdom made census data only available on a so-called ″cost recovery” basis, arguably imposing a continuing chill on what might have been a more robust market for GIS data. In recent years many countries have permitted more open access to geospatial data under the Aarhus Convention, which became law in October 2001. However, the only states that signed the agreement were from Europe and Asia.

A number of companies supplied GIS software that specialized in niche markets. For example, Caliper Corporation produced TransCAD, a software package focused on transportation planning and transportation GIS (GIS-T). Others, such as Idrisi, developed by Clark University in Worcester, MA, successfully catered to the academic market, providing detailed tutorials and accompanying datasets. It was during this period that the movement to introduce GIS instruction into the K-12 curriculum in the United States gathered momentum. These efforts were summarized and resource materials and advice for teaching GIS in primary and secondary schools were provided at the first national conference on the educational application of geographic information systems held in 1995 and sponsored by Technical Educational Research Centers (TERC). TERC has continued to provide educational resources to schools for all grade levels (and for university GIS courses as well) and now maintains an active website.

The era of geographic information science (GIScience): The mid-1990s saw a sea-change in the development of the academic discipline of GIS. In 1992, Goodchild published a major theoretical contribution when he argued that the discipline should move from a concern with the technology of geographic information systems to developing answers to questions that might more properly be considered to be part of a geographic information science. In the opening arguments of his paper, Goodchild stated that much of the early history of GIS was technology driven. It was concerned with how to get geographical data into an information system and with new technologies that were developed largely within government agencies, such as the CGIS and the US Census Bureau, and by remote sensing companies that were developing new technologies to acquire satellite imagery. Now, he argued, it was more appropriate to concentrate on the task of how to ″handle″ and exploit the data held in these GIS databases. The way forward was prepared by research that was being reported at a newly developed series of conferences, the International Geographical Union′s spatial data handling symposia (the first of these conferences was held in Zurich in 1984 and the 17th of these biennial meetings in Beijing in 2016). Goodchild presented a review of the nascent discipline of GIScience, including a synopsis of three decades of algorithmic research, into a series of topics: spatial data handling; data collection and management; data capture; spatial statistics; data modeling and theories of spatial data; data structures, algorithms and processes; data display (visualization); analytical tools; and, finally, institutional, managerial, and ethical issues. While some of these developments were to benefit from progress in computing (e.g., data display from a new emphasis on scientific visualization, often referred to as the second revolution in computer science), most launched new subdisciplines in geography (e.g., spatial statistics, which now produced new stand-alone software packages such as GeoDa, and new functionality in commercial software, such as Esri′s ArcGIS ToolBox, Spatial Analysis and GeoStatistical Analysis modules). Some of these new fields were now located in other academic departments such as information science and geomatics engineering, mirroring developments that had occurred decades before when fields such as geomorphology and climatology moved out of academic geography.

Within a few years a number of journals had changed their names to reflect this new emphasis on science as opposed to systems. For example, in 1997 the International Journal of Geographic Information Systems had replaced the word Systems in its name with Science. The new name was explained in the introduction to that volume by then editor, Peter Fisher, who acknowledged the debt to Goodchild′s seminal article in providing a rationale for the new focus to the journal and the discipline. The American

Cartographer, which had been launched in 1974, had changed its name in 1990 to Cartography and Geographic Information Systems. This lasted until 1999, when it also changed the Systems in its title to Science. Other journals, such as Transactions in GIS, circumvented the problem by leaving the acronym in their title undefined. When the 2nd edition of Geographical Information Systems: Principles, Techniques, Applications and Management appeared in 1999, the word Systems was retained, but when the same four authors published the first edition of a textbook two years later, they included both terms, Geographic Information Systems and Science (Longley et al. 2001). The Annals of the Association of American Geographers requests submissions in four broad areas, one of which is Methods, Models and Geographic Information Sciences but its Table of Contents retains the now more ambiguous acronym, GIS, and its specialty group in the field prevaricates, as well, with the title Geographic Information Science and Systems. The new NCGIA core curriculum, which gathered lectures for its website until 2000, also used geographic information science in its title. The lectures and associated material were now all online and no print copies were created. A note posted on the website in August 2000 stated that there would be no further updates due to new educational resources becoming available, including the digital library of Earth system education, the NCGIA′s own center for spatially integrated social science, and Esri′s virtual campus (Waters 2013). A review of progress in the field of GIScience, twenty years after the initial discussions of the concept, has been given by Goodchild (2010).

New educational initiatives also characterized this period. In 1990, the NCGIA board of directors recommended that a new organization be developed to assist researchers in GIScience. The UCGIS (University Consortium for Geographic Information Science) website, in its brief history of the organization, states that an ad hoc steering committee was formed by the NCGIA in 1991 containing 16 members from seven different disciplines. Unfortunately, this brief historical note does not list either the members of the committee nor the seven disciplines represented. In 1994, a founding meeting was held in Boulder, CO, and in 1995 the UCGIS was formally incorporated. The UCGIS had two primary objectives listed on its website: ″Advance research in the field of geographic information science" and to ″Build scholarly communities and networks to foster multidisciplinary GIS research and education." The membership of UCGIS has fluctuated over the years, reaching a high of perhaps 70 US universities in about 2005 but declining to 53 US universities at the time of writing. In the initial meetings it was made quite clear that this was a US organization and non-US universities would only be granted affiliate status. No Canadian university has ever been a member and at present there are only two non-US universities that have been awarded and retained affiliate status, CentroGeo in Mexico and the University of Salzburg′s department of geoinformatics.

The UCGIS has promoted annual meetings and symposia and, in partnership with the Association of American Geographers, the development of a body of knowledge (BoK) for teaching GIS. This was seen as a natural successor to the core curricula developed by the NCGIA. However, in conceptualization the BoK was vastly different. Waters (2013) provides a critical review of the development process that led to the publication of the BoK in 2006. The BoK was structured into ten knowledge areas that were then divided into 73 units that, in turn, were further subdivided into 330 topics. Contributors to the BoK had suggested that one of the primary weaknesses of the core curricula had been the lack of an explicit structure for continuous updating. Unfortunately, this was equally true of the BoK and it was not until the UCGIS held a special workshop at its summer symposium in Pasadena in 2014 that a new BoK was proposed with a formal timeline. In

the field of computer science there is a process for updating the curriculum approximately every six years. This has yet to be achieved by GIScience.

Nevertheless, by the end of the 1990s Mike Phoenix, former higher education specialist for Esri, was able to claim that their GIS software products were used in more than 60 different kinds of university academic and administrative departments (Waters 1998). By this date, GIS had influenced the teaching of many of the subdisciplines of geography and would, in the following decade, go on to influence the operations of many other disciplines that used spatial data.

Reactions to a formal geographic information science approach to GIS: Some academic geographers reacted with dismay to the new emphasis on geographic information science, seeing it as a reassertion of the aridity of the spatial paradigm of the so-called ″quantitative revolution,″ which had been disavowed by some members of the discipline in the 1970s. The most widely cited critique of the spatial paradigm within GIS came in the form of John Pickles edited volume, Ground Truth. Although some of the leading proponents of GIScience contributed essays to the book, most of the papers were written by academics unsympathetic to the achievements of those working in GIS.

Shortly after the publication of Ground Truth, the public participation in GIS (PPGIS) movement was launched at an NCGIA sponsored workshop held at the University of Maine. PPGIS may be defined as an approach to community planning that privileges the traditionally marginalized segments of society (the poor, the old, the young, the physically challenged, and members of ethnic minorities, among many others). It leverages GIS software to allow these individuals to participate in the planning of their communities and their environments. To achieve these goals PPGIS broadened traditional approaches to GIS by including a wide range of social science methodologies and theories. It is closely aligned with participatory GIS, a cognate set of methodologies and approaches and low-tech solutions, such as sketch maps, to the acquisition of geographic information. Typically PPGIS and PGIS involve the interaction and collaboration of academics with GIS expertise with members of the community wishing to participate in the planning of their communities. These approaches had antecedents, paradoxically in the later work of Bill Bunge, one of the pioneers of the quantitative revolution. PPGIS has also produced new lines of research, such as the current concern with the design of age-friendly communities.

In the twenty-first century, stimulated by the popularity of PPGIS, which had spawned a series of conferences in conjunction with the annual URISA meetings, GIS began to embrace a host of traditionally nonscientific approaches to geography, including qualitative, feminist, and critical GIS to name a few. PPGIS itself had rarely spelled out whether it was concerned with geographic information systems or science, the latter being somewhat of an anathema to those practicing PPGIS. The more important of these new approaches to GIS included formal adoptions of critical GIS and feminist approaches to the use of the technology. The possibility of the former was introduced in an article by Nadine Schuurman (2000) who identified three waves of criticism of the GIS community. She argued that the first wave had lasted from 1990 to 1994 and the debate had centered on the merits of the positivist approach adopted by GIS practitioners. The second wave occurred in the mid-1990s and represented the beginning of a dialogue between GIS specialists and those concerned with both the social effects and implications of GIS technology. The catalyst for this discourse was the NCGIA′s ″Research Initiative 19, GIS and Society: The Social Implications of How People, Space, and Environment Are

Represented in GIS." According to Schuurman, in the third wave, at the end of the 1990s, there was a greater commitment to the technology of GIS. This led to the rise of PPGIS in that decade and ever since. Quite separately, there was a call for a ″critical GIS" or ″GIS2" that would incorporate the various perspectives of social theorists (see Sheppard et al. (1999) for a discussion of the societal implications of the NCGIA′s Varenius Project, and also the papers in the special issue of Cartographica, 2009, 44(1)).

GIS developments since 2005: the world of volunteered GIS, web-based mapping and mobile GIS, and cloud computing and big data: Since 2005, developments in GIS have again mirrored the importance of progress in computing technology. Crowdsourcing and social networks have been hugely influential developments in the social application and individual use of computing technology, but these changes have been reflected in the move away from the use of authoritative data in GIS and the rise in influence and use of volunteered geographic information (VGI). The attractions of VGI are well described in Goodchild′s (2007) seminal paper on the topic: VGI is inexpensive, timely and available to all on the right side of the digital divide. Goodchild (2010), in reviewing progress in the field of GIScience, notes that the breaking down of the barriers between expert and nonexpert is also referred to as neogeography and that VGI itself has been called crowdsourced geographic information and community map- ping, and thus has strong links to PPGIS. VGI has been aided by the move to web-based mapping and the availability of online GIS technology such as ArcGIS Online and the almost universal availability of map-based apps on smartphones and in-car GPS navigation systems (see Miller (2007) for a review of these technologies that have produced a time–space convergence and aided the processes of globalization). GIS and computing hardware are becoming invisible technologies whose benefits can be leveraged and enjoyed seamlessly by wide sectors of the population in industrialized and developing countries.

Other software developments that have led to the almost universal use of geographic information and related technologies include Google Earth, OpenStreetMap, and software for finding directions, such as MapQuest. The familiarity of large sections of affluent populations with this type of software has led to the rise of location-based services and to new developments such as OpenImageMap and web mapping services.

Advances in computer technology, including cyberinfrastructure (leading to CyberGIS), cloud computing, and the rise in importance of ″big data," are almost immediately integrated into GIS software, with leading GIS companies such as Esri providing online guides to how big data may be used in such GIS applications as predictive modeling and social media. A review of the implications for the discipline of geography in general, and GIS in particular, specifically a move to a ″data driven" geography, is provided by Miller and Goodchild (2015). Traditionally, big data was concerned with the three ″Vs": volume, velocity, and variety. The terms are self-explanatory and geographic data often qualify on all three counts. More recently, computer scientists have added additional ″Vs" to the list, including veracity (relating to the provenance of the data: thus, for example, VGI might have lower veracity than authoritative data) (Miller and Goodchild 2015), value, validation (whether the data conforms to a priori model expectations), and voracity (the rate of ingestion, which is important in the use of virtual reality simulations with a GIS framework). Vagueness (or uncertainty) might also be added to the list as it is endemic to much GIS data.

GIS returns to its roots in geography and GIS: It can be argued that GIS has returned to its origins, from earlier concerns common to many geographers, at least on the human

geography side of the discipline. Miller and Goodchild (2015) summarize the history of geography′s concerns with idiographic (description-seeking) and nomothetic (law-seeking) approaches. At various times over the centuries one approach has been dominant and the other subordinate, disparaged, or overlooked. Miller and Goodchild argue that Strabo and Ptolemy were concerned with both approaches, for they provided detailed descriptions of specific places as well as generalizations that applied to the Earth or large regions. However, Miller and Goodchild also state that such an integration has rarely been adopted by researchers in the two millennia since Strabo and Ptolemy wrote. GIS, with its emphasis on software and algorithms and its concern with creating spatial databases, is seen by Miller and Goodchild as an intellectual activity that permits a dialogue between the idiographic and nomothetic world views. Perhaps this is best demonstrated in the various spatial interpolation algorithms, some of which produce global models (trend surface analysis, for example) while others emphasize local differences (e.g., geographically weighted regression). Miller′s (2007) call for a people-based approach to GIS also emphasizes individual differences.

A recent trend in GIS has been the recognition of the importance of geodesign. This is now the focus of a new series of conferences being held annually in Redlands and also in Europe and China. It has led to new undergraduate and graduate degree programs. Geodesign has been championed by Esri cofounder, Jack Dangermond, and reflects his graduate education in landscape architecture. Dangermond (2014) has defined geodesign as taking geographic information and linking ″it to the design, decision-making, and planning process using collaboration...by building the power of GIS into the process, allowing alternative plans to be visualized, compared, and evaluated.” He credits his former Harvard University professor Carl Steinitz as introducing him to ″this methodology” and so the history of GIS returns to its roots.

In 2007, the NSF began supporting research into ″transformative science.” There is little doubt that over the past fifty years GIS has been a transformative science for both the academic discipline of geography and the world we inhabit. The impact of GIS on the discipline of geography has been compared often to the impact of the telescope on astronomy but, as with the telescope, people choose what they want to see through the GIS lens. The NSF is interested in how transformative science has changed the world. It would behoove the disci- pline of geography to do as Sheppard et al. (1999) suggested and study how GIS has transformed the world.

Characteristics and Definition of Geographic Information Systems – GIS

Geographic Information Systems belong to information systems, distinguished by information about the location of objects and spatial relations between them. In addition, they allow for their cartographic presentation and conducting various types of analyses.

The Geographic Information System does not have one definite definition. There are many of them and, above all, they define GIS as an IT system, consisting of various methods of dealing with spatial data, the implementation of which requires hardware and software, as well as people who can operate it.

According to ***Clarke [1990]***, ″GIS is an automated system for collecting, storing, searching, analysing and displaying spatial data”.

Gaździcki [1990] defined this system as a system for acquiring, processing, verifying, integrating, manipulating, analysing and presenting data that are spatially referenced to the Earth. It usually includes a spatial database and appropriate software .

According to the definition given at the ***5th Scientific and Technical Conference PTIP*** ″GIS is an IT system sup- porting the collection, analysis and sharing of data about objects uniquely spatially located".

The basic functions of Geographic Information Systems include:

- data collection, verification and preliminary elaboration,
- data management,
- data processing and analysis,
- data visualization.

Acquiring data is usually carried out by direct measurements, methods and techniques of photogrammetry and remote sensing, GNSS technology, as a result of transfer from other systems or by using existing documentation in tabular form or in the form of maps. Descriptive data can be entered into the system interactively or by means of a batch. Acquiring and processing into a coherent form of the data model being created is often a long-term, costly process requiring considerable work. It is estimated that in many projects this phase requires up to 80% of time and costs. At the same time, this is the decisive stage for the quality of final results.
Access for digital files, it is possible thanks to the database management system. It allows you to supplement, search, update and organize data. One of the most important tasks in this field is to protect the system against data damage and access by unauthorized persons.
Transformation, analysis, aggregation and generalization can be distinguished among the processing functions. Some of the processing functions perform only operations on objects without changing them. Another group of processing functions generates (creates) new objects based on existing ones, and yet another can only modify existing objects.

The last group of basic function concerns the output of data in a specific form. This function is aimed at presenting data in an intelligible form to the user and making them available both in the form of paper printouts and in numerical form.

A characteristic feature of Geographic Information Systems is that they consist of five basic elements (Fig. 1).

The organization of spatial data in GIS is based on a layered structure – thematic layers – raster and vector (Fig. 2).



Fig. 1. Components of Geographic Information Systems

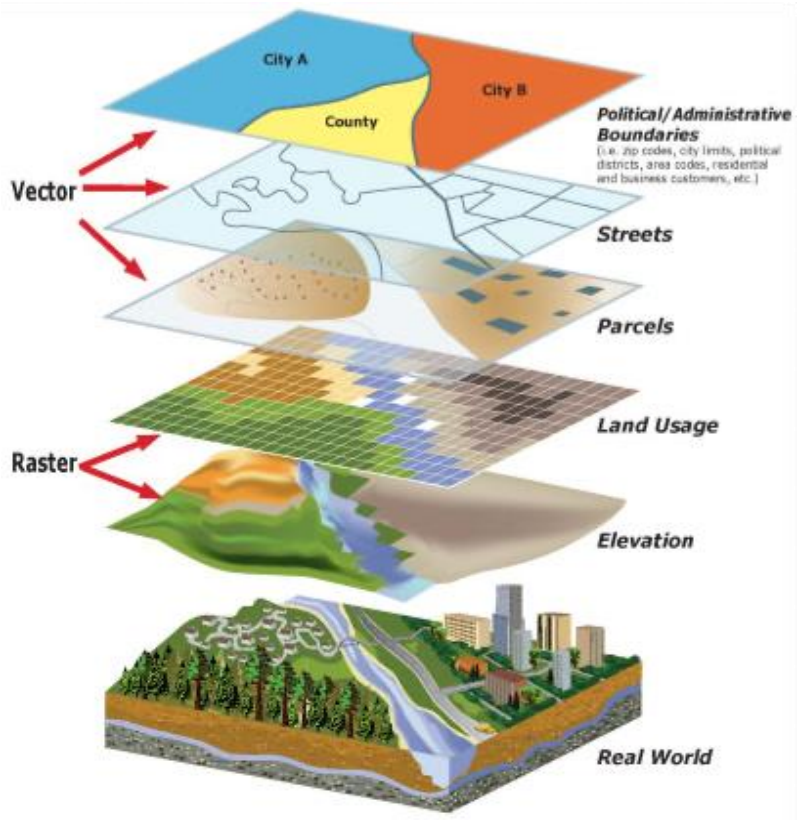


Fig. 2. Exemplary thematic layers in GIS; source: UNC Charlotte [undated]

GIS allows to integrate data from various sources but about the same object or phenomenon. This is possible only when the location is known, hence spatial reference to a specific place on the Earth's surface.

Geographical Information Systems allow to perform various types of spatial analysis, which gives them a universal character and a wide range of applications.

Components of GIS: A Geographic Information System (GIS) is a system wherein data related to earth, associated phenomena, and events is mapped and analyzed. It is a powerful system that incorporates spatial data, manages it, analyzes it, answers geographic queries and provides great visualization capability. There are five basic GIS components that make it effective.

- Hardware
- Software
- Data
- Methods
- People

Hardware: Hardware consists of the technical equipment needed to run a GIS efficiently. It includes computer/s (standalone / networked) with good configuration – good processing capability to run the GIS software, enough hard disk space to store large spatial data, and input and output devices such as scanners, printers, etc

Today, GIS runs on a wide range of hardware types, from centralized computer servers to desktop computers used in stand-alone or networked configurations. Minimum configuration required to Arc/Info Desktop 9.0 GIS application is as follows:

Product: ArcInfo Desktop 9.0

Platform: PC-Intel

Operating System: Windows XP Professional Edition, Home Edition Service Packs/Patches: SP 1

SP2 (refer to Limitations)

Shipping/Release Date: May 10, 2004

Hardware Requirements

CPU Speed: 800 MHz minimum, 1.0 GHz recommended or higher

Processor: Pentium or higher

Memory/RAM: 256 MB minumum, 512 MB recommended or higher

Display Properties: Greater than 256 color depth

Swap Space: 300 MB minimum

Disk Space: Typical 605 MB NTFS, Complete 695 MB FAT32 + 50 MB for installation

Browser: Internet Explorer 6.0 Requirement:

(Some features of ArcInfo Desktop 9.0 require a minimum installation of Microsoft Internet Explorer Version 6.0.)

Software: GIS software provides the functions and tools needed to store, analyze, and display geographic information. Key software components are (a) a database management system (DBMS) (b) tools for the input and manipulation of geographic information (c) tools that support geographic query, analysis, and visualization (d) a graphical user interface (GUI) for easy access to tools. GIS software are either commercial software or software developed on Open Source domain, which are available for free. However, the commercial software is copyright protected, can be expensive and is available in terms number of licensees.

Currently available commercial GIS software includes Arc/Info, Intergraph, MapInfo, Gram++ etc. Out of these Arc/Info is the most popular software package. And, the open source software are AMS/MARS etc.

Data: The most important GIS component is the data – how it is managed and accessed. Data is stored as geographic data (spatial data) and related tabular data (non-spatial data). Data comes in various formats, and GIS integrates such spatial data and non-spatial data by using DBMS. It is the key functionality of GIS that helps in organizing, managing and accessing data.

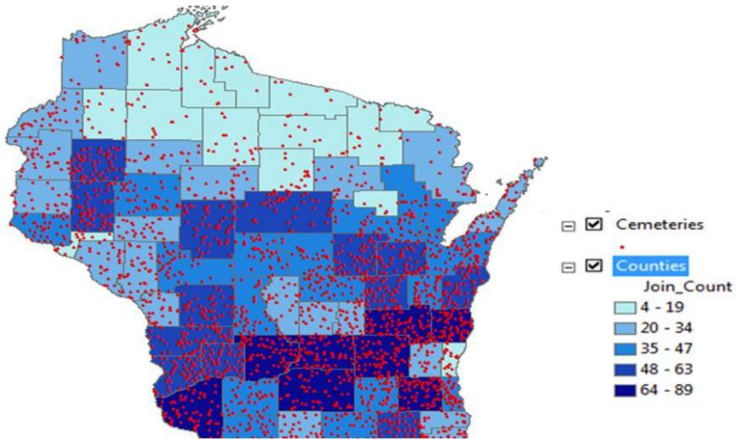
Methods: To make a GIS system work properly requires not only the necessary investments in hardware, software and data, but also requires knowledge to utilize the GIS technology. The methods are the procedure followed to answer the question need to be resolved. Method in GIS includes how the data will be accessed, stored, managed, processed, analyzed, and finally presented as output for particular application.

People: People in GIS are technical persons (GIS managers, database administrators, specialists, analysts, and programmers) who design and maintain the GIS work and those who use it. They are the ones who make GIS work.

People in GIS can be categorized into: viewers – the people who just use GIS for reference; general users – who use GIS for business, services, and making decisions such as planners, scientists, engineers, etc; GIS specialists: who are the backbone of GIS and maintain, process and analyze geographic data. They provide technical support to the users.

What can we do with GIS? GIS can be used as tool in both problem solving and decision making processes, as well as for visualization of data in a spatial environment. Geospatial data can be analyzed to determine (1) the location of features and relationships to other features, (2) where the most and/or least of some feature exists, (3) the density of features in a given space, (4) what is happening inside an area of interest (AOI), (5) what is happening nearby some feature or phenomenon, and (6) and how a specific area has changed over time (and in what way).

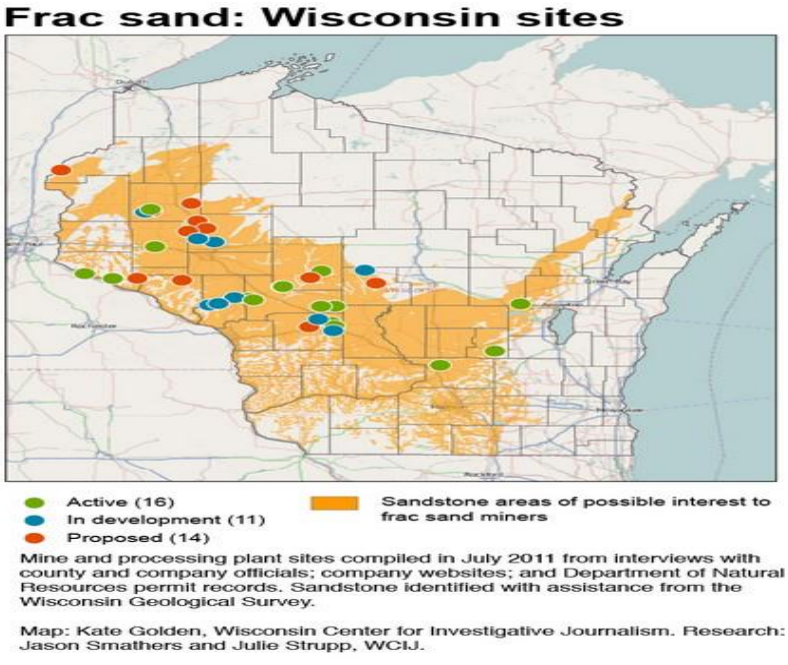
1. **Mapping where things are:** We can map the spatial location of real-world features and visualize the spatial relationships among them. Example: below we see a map of frac sand mine locations and sandstone areas in Wisconsin. We can see visual patterns in the data by determining that frac sand mining activity occurs in a region with a specific type of geology.



2. **Mapping quantities**:

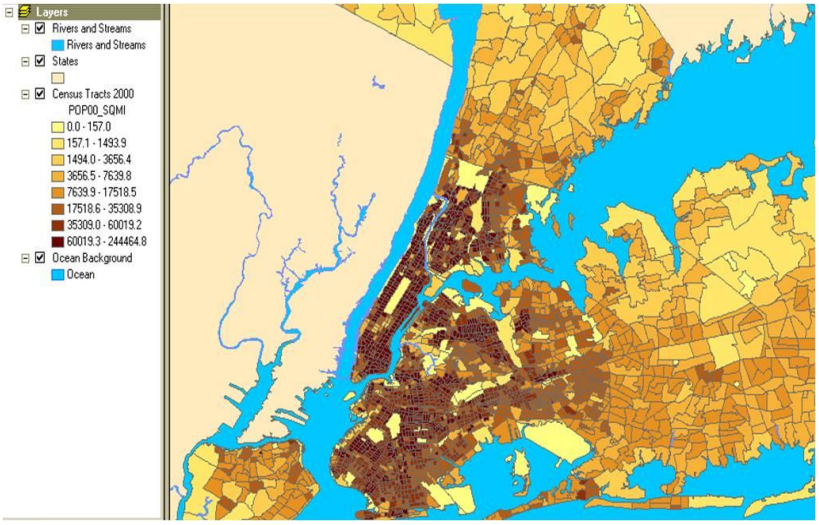
People map quantities, such as where the most and least are, to find places that meet their criteria or to see the relationships between places.

Example: below is a map of cemetery locations in Wisconsin. The map shows the cemetery locations as dots (dot density) and each county is color coded to show where the most and least are (lighter blue means fewer cemeteries).



3. **Mapping densities:** Sometimes it is more important to map concentrations, or a quantity

normalized by area or total number. Example: Below we have mapped the population density of Manhattan (total population counts normalized by the area in sq. miles of census tracts.)



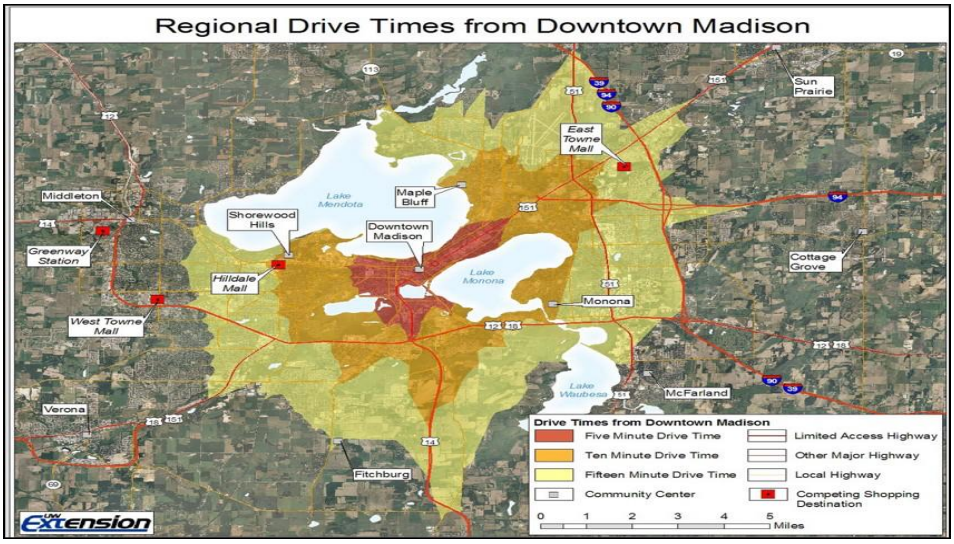
4. **Finding what is inside**:

We can use GIS to determine what is happening or what features are located inside a specific area/region. We can determine the characteristics of "inside" by creating specific criteria to define an area of interest (AOI). Example: below is a map showing a flood event and the tax parcels and buildings in the floodway. We can use tools like CLIP to determine which parcels fall inside the flood event. Further, we can use attributes of the parcels to determine potential costs of property damage.



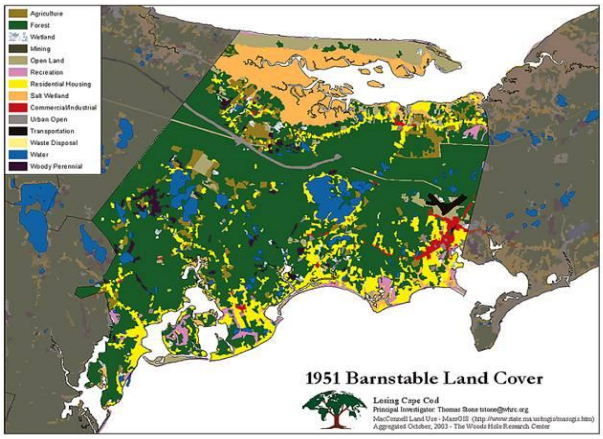
5. **Finding what is nearby**:

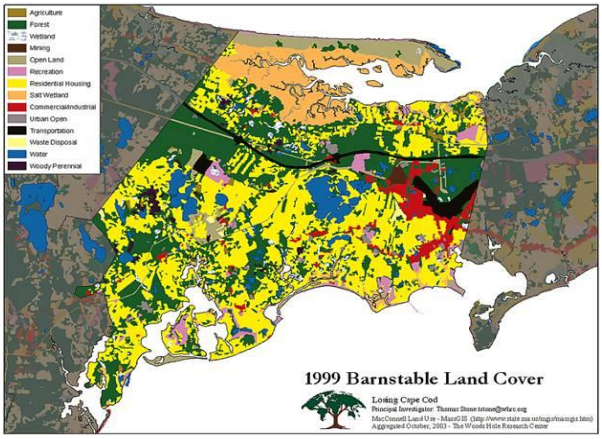
We can find out what is happening within a set distance of a feature or event by mapping what is nearby using geoprocessing tools like BUFFER. Example: below we see a map of drive times from a central location in the City of Madison, WI. We can use streets as a network and add specific criteria like speed limit and intersection controls to determine how far a driver can typically get in 5, 10, or 15 minutes. (Map courtesy of UW Extension)



6. **Mapping change**:

We can map the change in a specific geographic area to anticipate future conditions, decide on a course of action, or to evaluate the results of an action or policy. Example: below we see land use maps of Barnstable, MA showing changes in residential development from 1951 to 1999. The dark green shows forest, while bright yellow shows residential development. Applications like this can help inform community planning processes and policies.





GIS Technology: Advantages and Disadvantages

GIS is a computer-based application for mapping and analyzing geographically referenced data in the form of digitized three-dimensional operations. The use of GIS has become inevitable in almost every geospatial application. The end-user community is interested in exploring the economic and deliberate value of GIS due to the benefits of this rapidly growing technology. The fundamental advantages of GIS can be generalized as follows:

- It is easy to visualize the spatial information represented by GIS output maps with clear legends and different groups of coloring and patterns. Thus the novice users of GIS could be comfortable with its application. Expert use of the GIS application is highly supportive in all kinds of environment.

- GIS can build various themes and is supportive for database operations such as creation, updating, and manipulation. The map accuracy depends on the quality of input data.

- GIS offers an influential decision-making tool in the education sector for its administration, policy making, and instruction. For administrators, GIS can offer an approach to visualize and manage systems in their entirety, including monitoring campus safety, mapping campus buildings, surveilling cable and other infrastructures, routing school buses, planning school closures and opening new ones, and outlining strategies for recruitment. For policymakers in education, GIS provides them with tools that can present patterns in educational achievement and guide the targeting of new programs.

- Groundwater analysis uses GIS to interpret spatial correlation targeting potential groundwater resources as well as determining water quality. A logical approach can be adapted for the efficient management of water resources, such as surface and subsurface delineations. GIS can be applied to site selection, zoning, planning, and conservation measures.

- Geophysical parameters on the subsurface conditions can be incorporated with spatial data and interpolation techniques can be applied to the exploration, assessment, and prediction of groundwater resources, as well as to the selection of an artificial recharge site. The subsurface flow and pollution model guides how to assess hazards and helps in planning the preventive measures with the help of GIS and geostatistical technologies.

- GIS methods can predict, assess risk, and identify hazardous locations of natural resources. It further integrates the spatial and nonspatial data to enable better understanding of emergency conditions. It also supports analysis and the creation of preventive and mitigating solutions.

- GIS can be used in criminology to identify facts. Some spatial analyses uses underlying social phenomena to identify rates of crime, which necessitates the use of boundary units such as census tracts and police beats. Although some researchers have also recognized that a simple spatial concentration of crime can also be valuable.

- GIS creates employment opportunities in education, administration, research, government, and nonprofit organizations.

- GIS technologies refine datasets, data models, and the relation between attributes. High standards are achieved with the scope for generation of newer objects on an on-demand basis. It also allows existing attributes to be linked with newly defined datasets.

Disadvantages of Geographic Information Systems:

- *Expensive*:

  GIS setup is complex, in addition to the cost of the equipment, there is the cost incurred in training. Frequent updating of datasets or data models may lead to errors in results.

- *Real-time parameters*:

  The handling of growing datasets is an overall challenge to the GIS system. Geographical errors increase with larger-scale data: The quality of the data collected directly affects the accuracy of the end system. Geographic errors will also affect net results since GIS handles large-scale data.
  Relative loss of resolution: Every technology has negotiable errors when deployed.
  Positional accuracy and precision: Accuracy and precision are the functions of the scale at which a map (paper or digital) is created. The nonspatial data linked to location may also be inaccurate or imprecise. Inaccuracies may result from mistakes of many sorts. Nonspatial data can also vary greatly in precision. Precise attribute information describes phenomena in great detail.

- ***Violation of privacy*:**

  The user community is not limited to authorized persons. So there is threat in the usage of data displayed from the GIS system.

- Error-prone interpretation could lead to failure of system implementation thus affecting the economic strategy of the implementer.

- There might be failures in initiating or additional effort required in order to fully implement the GIS but there might be large benefits to anticipate as well.

- There is a lack of trained teachers in the domain. Though GIS and remote sensing have been introduced in some universities across the country, still the subjects have not been taught to the fullest extent. Moreover, a link between secondary education and higher education must be established for a wide spread and its continuity in the system. Prior knowledge of GIS is a prerequisite to train the trainers.

Geographical terms: Geographical information in digital formats requires the standardization of criteria and the incorporation of minimum parameters that guarantee its quality and also allow interoperability between users to optimize its use and exchange, leading to the reuse and democratization of information.

The following is a glossary of the most relevant geographical terms. Some terms come from the technical series "Geographic Information Standards" published by

SENPLADES (2013) in its section "Terminology for Geographic Information", which are based on ISO / TS 19104: 2008 Geographic information - Terminology and ISO / TC 211 Multi-Lingual Glossary of Terms.

- **Band:** Each of the parts into which the electromagnetic spectrum is divided to enable the sensors to capture the electromagnetic radiation. The radiation data (numerical values) captured for each defined band are usually organized as raster files (Moreno Jiménez, 2008).

- **Layer**: Basic unit of geographic information that can be requested as a map from a server [ISO 19128:2005]. Conceptually, a layer is a portion or stratum of geographic space in a particular area, and could be considered the equivalent of an element of the legend of the map (SENPLADES, 2013).

- **Coordinate:** Measured value on the earth's surface that serves to determine the position of any point on it and, consequently, with respect to the position of any other place. To determine these values imaginary lines, perpendicular to each other, are used. These are termed parallels and meridians, whose intersection defines the position of the point in the coordinate system (López Trigal, 2015).

- **Datum:** Parameter or set of parameters that define the position (A.282) of the origin, scale and orientation of a coordinate system [ISO 19111:2007].

- **Vertical datum:** Datum describing the relationship of height related to gravity or depth with the Earth. NOTE: In most cases, the vertical datum is related to the mean sea level. The geodesic heights are treated in relation to a three-dimensional ellipsoidal coordinate system that refers to a geodetic datum [ISO 19111:2007].

- **Ellipsoid:** Surface formed by the rotation of an ellipse around a main axis. NOTE: In this international standard, the ellipsoids are always oblong, which means that the axis of rotation is always the minor axis [ISO 19111:2007].

- **Scale:** Relationship between the magnitudes of the elements represented on the map and those that they have in reality. It defines the reduction to which the earth's surface must be submitted to be able to represent it in a document or on a map, whose size is much smaller. The representation of the scale on a map can be graphical or numerical (López Trigal, 2015).

- **Geopositioning:** Retrieving the geographic position of an object [ISO/TS 19130:2010].

- **Georeferencing:** Operation of obtaining and assigning geographical coordinates to information (usually a layer) that lacks it. Usually applied to place Earth images or events associated with postal addresses (Moreno Jiménez, 2008).

- **Image:** Raster type coverage whose attribute values are a numeric representation of a physical parameter [ISO 19115-2:2009].

- **Latitude:** Usually represented by the greek letter φ (capital letter fi), latitude is the angle formed from the center of the Earth on the meridian plane by the normal to the ellipsoid at the point considered and the plane of the equator. All points on the

Earth's surface with equal latitude define the parallel lines. The measure is expressed in sexagesimal notation starting from the equator, positive towards the north (0° to 90°) and negative towards the south (0° to -90°) (Del Bosque González et al. 2012).

- **Legend:** Application of a classification (A.52) in a specific area using a defined map scale and a specific set of data [ISO 19144-1:2009].

- **Longitude:** Usually represented by the greek letter λ (lambda), longitude is the dihedral angle, formed from the center of the Earth on the plane of the equator, between the meridian containing the point and the meridian taken as the origin. The plane of the equator is that which passes through the center of the Earth and is perpendicular to the axis of rotation. The meridians are lines formed by all points of equal length, and represent the intersection of the Earth's surface with planes perpendicular to the plane of the equator and containing the axis of rotation (Del Bosque González et al. 2012).

- **Digital terrain model and digital elevation model:** A digital terrain model is a spatial representation of a quantitative and continuous variable, such as temperature, elevation, or atmospheric pressure. In particular, when the variable to be represented is the elevation of the terrain, it is called the Digital Elevation Model or DEM. Therefore, a digital elevation model is a numerical data structure that represents the spatial distribution of the altitude of the terrain surface (Mancebo, Ortega, Martín, & Valentín, 2008).

- **Slope:** Relation of elevation change with respect to the length of the curve [ISO 19133:2005].

- **Cartographic projection:** Geometric operation that allows the curved surface of the earth (three-dimensional) to be represented on a flat (two-dimensional) surface. This procedure is used to transform the angular coordinates with which the location of the geographic objects is determined on the terrestrial globe into plane coordinates that allow the cartographic representation on a surface of two dimensions (López Trigal, 2015).

- **Remote sensing:** In a broad sense it can be defined as the acquisition of information about an object at a distance, that is, without there being material contact between the observed object or system and the observer (Sobrino, 2000).

The evolution of GIS as a discipline: At first, GIS was just a combination of ideas from quantitative cartography, and the computer systems that existed at that time. It was basically the work of cartographers and geographers who tried to adapt their knowledge and their needs to a technology that looked promising. Since then, a large number of other disciplines have contributed to the field of GIS and their contributions are as important, or in some cases even more so, than those of cartography and geography.

More or less at the same time, society was becoming more concerned about the environment and the effect of human actions on it. This influenced GIS which was becoming a fundamental tool for all tasks related to environmental management (land-use planning, environmental monitoring, etc.), and boosted its development.

At the beginning of the seventies, once it was clear that GIS had a great future ahead, the field of GIS started to shape its identity and to become a solid discipline. The first conferences and symposiums about GIS took place and GIS was already included in University curricula. Specialized journals and forums appeared in the eighties and helped spread GIS to a wider audience, The industry of GIS consolidated itself in the seventies. ESRI (Environmental Systems Research Institute), pioneer and current leader of the GIS market, was founded is 1969, and its products have played a key role in the popularization of GIS. The first open-source GIS, GRASS (Geographic Resources Analysis Support System), appeared in 1985.

The beginning of the 21st century marks a turning point in the history of GIS, as it reaches non-professional audiences. Cartography services such as Google Maps allow users with little or no technical GIS knowledge to interact with a GIS application and use it. GPS navigators, which include both analysis and rendering capabilities that come from GIS, are another good example of this.

The evolution of technology: The evolution of computers has affected GIS. Three are the main areas that have had a major influence in shaping GIS as we know it now.

Graphical outputs. The capabilities of computers to generate graphical outputs have greatly improved since their beginnings, and they are still evolving. GIS has followed this evolution closely, both for screen rendering and for the case of printed outputs.

Data access and storage. The size of GIS datasets has increased enormously, and using these large datasets would not be possible without the corresponding improvements in both data storage and data access.

Data input. In the early days of GIS, data were manually digitized. Nowadays, creating data that can be used in a GIS is a completely different process, and it uses specific hardware such as high-resolution scanners, or specific software such as the one used for automatic digitalization of pattern recognition based on images, all of which generate ready-to-use data.

Along with this, software has changed following the evolution of computers themselves, from mainframes to personal computers, and more recently, to other platforms such as tablets or mobile phones.

By the end of the eighties, cartography can be efficiently produced in personal computers, with a comparatively low cost, without the need of expensive and dedicated large mainframes.

Nowadays, the combination of positioning systems such as GPS with mobile platforms is playing and important role in the development of GIS, in areas such as data collection.

The Internet also changed GIS, much like it changed every other field, whether scientific or not. In 1993, Xerox PARC, the first map server to distribute cartography over the Internet, was created. The first digital on-line atlas, the Canadian National Atlas, has been available since 1994. More recently, the ideas of the Web 2.0 are adapted to the field of GIS and contribute to the development of what is now known as Web Mapping.

The evolution of data: The first geographical datasets used in GIS contained just scanned maps and digitized features obtained from them. Since then, new data sources have been constantly appearing, with formats that are better adapted to GIS, and with GIS

itself adapting to them as well. As a consequence of that, the amount, precision, and quality of data that is now available to be used in a GIS has dramatically increased.

The launching of the first earth observation satellites represents a key advance. The techniques that were already in use for aerial photography, developed mostly during the First World War (although the discipline goes back to the second half of the 19th century, when photos were taken from hot air balloons), are applied on a global scale when the first satellites are created. SPOT Image, the first commercial company to distribute satellite images that cover the entire globe, was created in 1982.

Positioning technologies are another important data source for GIS. In 1981, the GPS system became completely operative, and in 2001, its accuracy for civil use was increased.

As it happened with GIS software, digital geographical data becomes more popular and receives more attention. In 1976, the United States Geological Service (USGS) publishes its first Digital Elevation Models (DEM), in response to the high relevance that this type of data now had in the context of geographical analysis. In 2000, elevation data from the Shuttle Radar Topographic Mission(SRTM) is released to the public, covering 80% of the Earth's surface with a resolution of one arc second (about 30 meters).

The development of techniques such as LiDAR, which can be used to get elevation data with much more detail, opens a large array new possibilities for areas such as terrain analysis.

The evolution of data is not just technical, but also social and organizational. As the amount of data increases, it becomes clear that new strategies must be developed for managing those data. So-called Spatial Data Infrastructures are developed as a result of this. The most relevant of them is the United States National Spatial Data Infrastructure (NSDI), created in 1994. In Europe, the INSPIRE directive serves a similar purpose.

Many of these activities and developments follow the specifications set up by the Open GIS Consortium (OGC), and international consortium founded in 1994, which works to homogenize and standardize the use and distribution of geographical data.

The evolution of theories and techniques: Once the first GIS was implemented and could respond to the data management and analysis needs for which they were created, new techniques and approaches began to be developed. Spatial analysis is a comparatively recent field. In 1854, John Snow performed what is usually considered one of the first examples of analytical cartography, when he used a map to determine the source of a cholera outbreak in London.

In his book Design with Nature (1969), Ian McHarg defined the basic ideas about map overlays, which, as we will later see, are fundamental for the analysis and visualization of geographical data layers within a GIS. Terrain analysis is another field that has experienced a huge qualitative change thanks to GIS. Traditional terrain analysis, mostly based on geology and geomorphological analysis, developed into a quantitative science focused on the morphometric analysis of relief.

Along with the analytical component, cartography also evolved in the context of GIS. In 1819, Pierre Charles Dupin created the fist choropleth map. With the arrival of GIS, this type of map will become very popular. The advances in Computer-Assisted Design (CAD) applications and in-screen rendering techniques helped in defining a new discipline: computational geometry. GIS vector analysis is based on it.

Nature of Geographic Information: This part reviews the basic fundamentals of geographic data and information. The focus is on understanding the basic structure of geographic data, and how issues of accuracy, error, and quality are paramount to properly using GIS technology. The establishment of a robust database is the cornerstone of a successful GIS.

- Maps and Spatial Information
- Characterizing Geographic Features
- Spatial Data Accuracy and Quality

Maps and Spatial Information: The main method of identifying and representing the location of geographic features on the landscape is a map. A map is a graphic representation of where features are, explicitly and relative to one another. A map is composed of different geographic features represented as either points, lines, and/or areas. Each feature is defined both by its location in space (with reference to a coordinate system), and by its characteristics (typically referred to as attributes). Quite simply, a map is a model of the real world.

The map legend is the key linking the attributes to the geographic features. Attributes, e.g. such as the species for a forest stand, are typically represented graphically by use of different symbology and/or color. For GIS, attributes need to be coded in a form in which they can be used for data analysis (Burrough, 1986). This implies loading the attribute data into a database system and linking it to the graphic features.

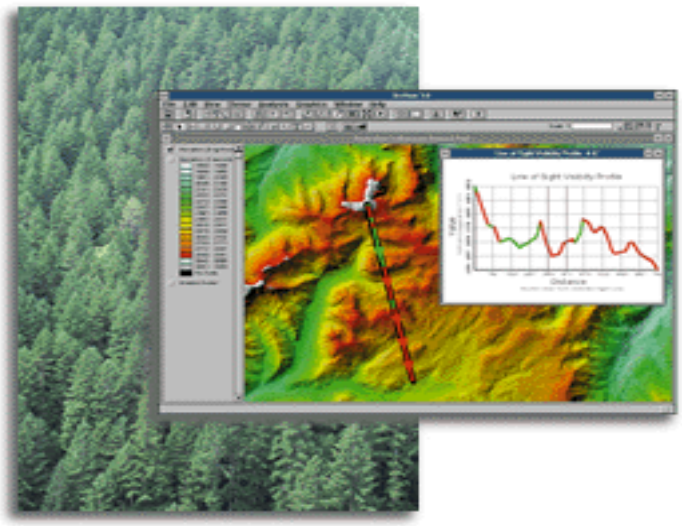


Fig: Maps are simply models of the real world. They represent snapshots of the land at a specific map scale. The map legend is the key identifying which features are represented on a map.

For geographic data, often referred to as spatial data, features are usually referenced in a coordinate system that models a location on the earth's surface. The coordinate system may be of a variety of types. For natural resource applications the most common are:

Geographic coordinates such as latitude and longitude, e.g. 56°27'40" and 116°11’25”. These are usually referred by degrees, minutes, and seconds. Geographic coordinates can also be identified as decimal degrees, e.g. 54.65°.

A map projection, e.g. Universe Transverse Mercator (UTM) where coordinates are measured in metres, e.g. 545,000.000 and 6,453,254.000 normally reference to a central meridian. Eastings refer to X coordinates while Northings refer to Y coordinates.

A legal survey description, e.g. Meridian, Township, Range such as the Alberta Township System, e.g. Township 075 Range 10 West of 4th Meridian.

Geographic data is distinguished from attribute data in that it is referenced spatially by a coordinate system, e.g. it has a spatial extent. Natural resource applications commonly use a Legal Survey system, e.g. the Alberta Township System (ATS), which identifies feature's locations as being a Meridian, Township, and a Range; or a projection such as the UTM coordinate system which identifies features by an Easting coordinate (X) and a Northing coordinate (Y) in a particular UTM zone.

In the UTM projection the area of the earth between 80 degrees North and 80 degrees South latitude is divided into north-south columns 6 degrees of longitude wide called zones. These are numbered 1 to 60 eastward beginning at the 180th meridian. Within each zone the central meridian is given an Easting value of 500,000 metres. The equator is designated as having a Northing value of 0 for northern hemisphere coordinates. Coordinates are recorded relative to the central meridian in metres in a particular zone. The basis of the UTM projection defines that the coordinates are duplicated within each UTM zone. Accordingly, use of the UTM projection is only appropriate for certain spatial extents and scales of data. It is not appropriate to use this projection if your area of interest crosses UTM zone boundaries.

For example, the province of Alberta is located in UTM zones 11 and 12. The central meridian for zone 11 is 117° longitude. The central meridian for zone 12 is 111° longitude. The UTM coordinate system is the most widely used projection in the mapping industry and consequently is becoming an de facto standard for use with geographic information systems. This is particularly true for regional data in Canada. The State Plane coordinate system is widely used in the United States.

Maps are the traditional method of storing and displaying geographic information.

A map portrays 3 kinds of information about geographic features. The:

- Location and extent of the feature
- Attributes (characteristics) of the feature
- Relationship of the feature to other features.

Geography has often been described as the study of why what is where. This description is quite appropriate when considering the three kinds of information that are portrayed by the traditional map;

- The **location and extent** of a feature is identified explicitly by reference to a coordinate system representing the earth's surface. This is **where** a feature is.

- The **attributes** of a feature describe or characterise the feature. This is **what** the feature is.

- The relationship of a feature to other features is implied from the location and attributes of all features. Relationships can be defined explicitly, e.g. roads connecting towns, regions adjacent to one another, or implicitly, e.g. close to, far from, similar to, etc. Implicit relationships are interpreted according to the knowledge that we have about the natural world. Relationships are described as **how** or **why** a feature is.

The geographic information system distinguishes between the spatial and attribute aspect of geographic features.

Characterizing Geographic Features: All geographic features on the earth's surface can be characterized and defined as one of three basic feature types. These are points, lines, and areas.

Point data exists when a feature is associated with a single location in space. Examples of point features include a fire lookout tower, an oil well or gas activity site, and a weather station.

Linear data exists when a feature's location is described by a string of spatial coordinates. Examples of linear data include rivers, roads, pipelines, etc.

Areal data exists when a feature is described by a closed string of spatial coordinates. An area feature is commonly referred to as a *polygon*. Polygonal data is the most common type of data in natural resource applications. Examples of polygonal data include forest stands, soil classification areas, administrative boundaries, and climate zones. Most polygon data is considered to be homogeneous in nature and thus is consistent throughout.

Data Accuracy and Quality: The quality of data sources for GIS processing is becoming an ever increasing concern among GIS application specialists. With the influx of GIS software on the commercial market and the accelerating application of GIS technology to problem solving and decision making roles, the quality and reliability of GIS products is coming under closer scrutiny. Much concern has been raised as to the relative error that may be inherent in GIS processing methodologies. While research is ongoing, and no finite standards have yet been adopted in the commercial GIS marketplace, several practical recommendations have been identified which help to locate possible error sources, and define the quality of data. The following review of data quality focuses on three distinct components, data accuracy, quality, and error.

Accuracy: The fundamental issue with respect to data is accuracy. Accuracy is the closeness of results of observations to the true values or values accepted as being true. This implies that observations of most spatial phenomena are usually only considered to estimates of the true value. The difference between observed and true (or accepted as being true) values indicates the accuracy of the observations.

Basically two types of accuracy exist. These are positional and attribute accuracy. Positional accuracyis the expected deviance in the geographic location of an object from its true ground position. This is what we commonly think of when the term accuracy is discussed. There are two components to positional accuracy. These are relative and absolute accuracy. Absolute accuracy concerns the accuracy of data elements with respect

to a coordinate scheme, e.g. UTM. Relative accuracy concerns the positioning of map features relative to one another.

Often relative accuracy is of greater concern than absolute accuracy. For example, most GIS users can live with the fact that their survey township coordinates do not coincide exactly with the survey fabric, however, the absence of one or two parcels from a tax map can have immediate and costly consequences.

Attribute accuracy is equally as important as positional accuracy. It also reflects estimates of the truth. Interpreting and depicting boundaries and characteristics for forest stands or soil polygons can be exceedingly difficult and subjective. Most resource specialists will attest to this fact. Accordingly, the degree of homogeneity found within such mapped boundaries is not nearly as high in reality as it would appear to be on most maps.

Quality: Quality can simply be defined as the fitness for use for a specific data set. Data that is appropriate for use with one application may not be fit for use with another. It is fully dependant on the scale, accuracy, and extent of the data set, as well as the quality of other data sets to be used. The recent U.S. Spatial Data Transfer Standard (SDTS) identifies five components to data quality definitions. These are:

- Lineage
- Positional Accuracy
- Attribute Accuracy
- Logical Consistency
- Completeness

Lineage: The lineage of data is concerned with historical and compilation aspects of the data such as the:

- Source of the Data;
- Content of the data;
- Data capture specifications;
- Geographic coverage of the data;
- compilation method of the data, e.g. digitizing versus scanned;
- transformation methods applied to the data; and
- the use of an pertinent algorithms during compilation, e.g. linear simplification, feature generalization.

Positional Accuracy:

The identification of positional accuracy is important. This includes consideration of inherent error (source error) and operational error (introduced error). A more detailed review is provided in the next section.

Attribute Accuracy:

Consideration of the accuracy of attributes also helps to define the quality of the data. This quality component concerns the identification of the reliability, or level of purity (homogeneity), in a data set.

Logical Consistency:

This component is concerned with determining the faithfulness of the data structure for a data set. This typically involves spatial data inconsistencies such as incorrect line intersections, duplicate lines or boundaries, or gaps in lines. These are referred to as spatial or topological errors.

Completeness:

The final quality component involves a statement about the completeness of the data set. This includes consideration of holes in the data, unclassified areas, and any compilation procedures that may have caused data to be eliminated.

Error:

Two sources of error, inherent and operational, contribute to the reduction in quality of the products that are generated by geographic information systems. Inherent error is the error present in source documents and data. Operational error is the amount of error produced through the data capture and manipulation functions of a GIS. Possible sources of operational errors include:

- Mis-labelling of areas on thematic maps;
- misplacement of horizontal (positional) boundaries;
- human error in digitizing;
- classification error;
- GIS algorithm inaccuracies; and
- Human bias.

While error will always exist in any scientific process, the aim within GIS processing should be to identify existing error in data sources and minimize the amount of error added during processing. Because of cost constraints it is often more appropriate to manage error than attempt to eliminate it. There is a trade-off between reducing the level of error in a data base and the cost to create and maintain the database.

An awareness of the error status of different data sets will allow user to make a subjective statement on the quality and reliability of a product derived from GIS processing.

The validity of any decisions based on a GIS product is directly related to the quality and reliability rating of the product.

Depending upon the level of error inherent in the source data, and the error operationally produced through data capture and manipulation, GIS products may possess significant amounts of error.

Often because GIS data is in digital form and can be represented with a high precision it is considered to be totally accurate. In reality, a buffer exists around each feature which represents the actual positional location of the feature. For example, data captured at the 1:20,000 scale commonly has a positional accuracy of +/- 20 metres. This means the actual location of features may vary 20 metres in either direction from the identified position of the feature on the map. Considering that the use of GIS commonly involves the integration of several data sets, usually at different scales and quality, one can easily see how errors can be propagated during processing.

Example of areas of uncertainty for overlaying data:

Several comments and guidelines on the recognition and assessment of error in GIS processing have been promoted in papers on the subject. These are summarized below:

- There is a need for developing error statements for data contained within geographic information systems (Vitek et al, 1984).
- The integration of data from different sources and in different original formats (e.g. points, lines, and areas), at different original scales, and possessing inherent errors can yield a product of questionable accuracy (Vitek et al, 1984).
- The accuracy of a GIS-derived product is dependent on characteristics inherent in the source products, and on user requirements, such as scale of the desired output products and the method and resolution of data encoding (Marble, Peuquet, 1983).
- The highest accuracy of any GIS output product can only be as accurate as the least accurate data theme of information involved in the analysis (Newcomer, Szajgin, 1984).
- Accuracy of the data decreases as spatial resolution becomes more coarse (Walsh et al, 1987); and
- As the number of layers in an analysis increases, the number of possible opportunities for error increases (Newcomer, Szajgin, 1984).

GIS Data Models:

A GIS stores information about the world as a collection of thematic layers that can be linked together by geography. This simple but extremely powerful and versatile concept has proven invaluable for solving many real-world problems from tracking delivery vehicles, to recording details of planning applications, to modeling global atmospheric circulation. The thematic layer approach allows us to organize the complexity of the real world into a simple representation to help facilitate our understanding of natural relationships.

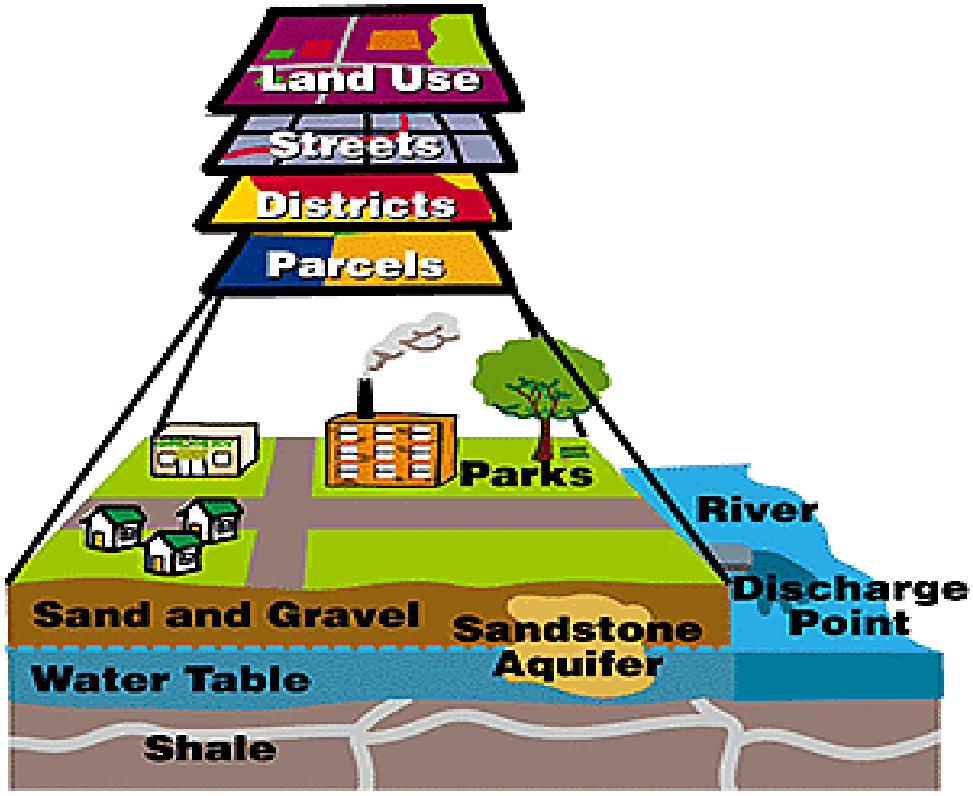


Fig: The thematic layer approach allows us to organize the complexity of the real world

GIS Data Types:

The basic data type in a GIS reflects traditional data found on a map. Accordingly, GIS technology utilizes two basic types of data. These are:

Spatial data: describes the absolute and relative location of geographic features

Attribute data: describes characteristics of the spatial features. These characteristics can be quantitative and/or qualitative in nature. Attribute data is often referred to as tabular data.

The coordinate location of a forestry stand would be spatial data, while the characteristics of that forestry stand, e.g. cover group, dominant species, crown closure, height, etc., would be attribute data. Other data types, in particular image and multimedia data, are becoming more prevalent with changing technology. Depending on the specific content of the data, image data may be considered either spatial, e.g. photographs, animation, movies, etc., or attribute, e.g. sound, descriptions, narration's, etc.

Spatial Data Models:

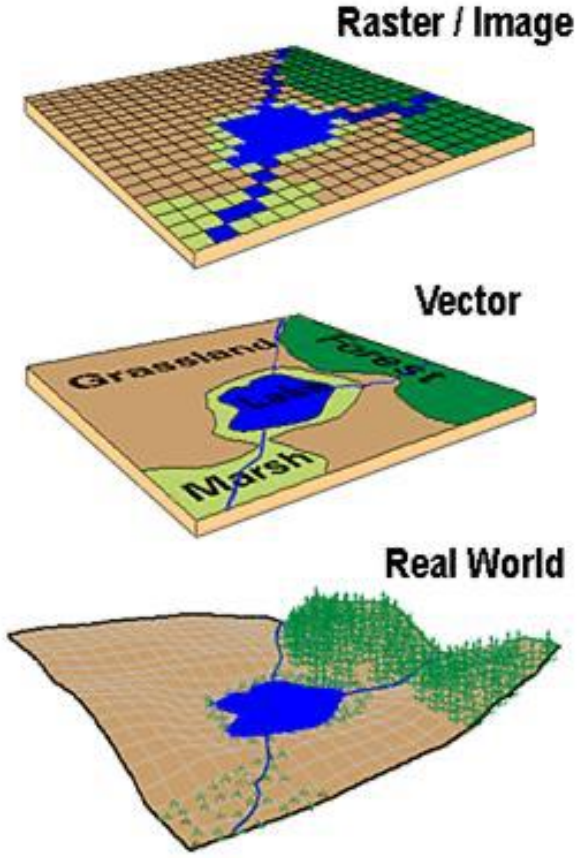
Traditionally spatial data has been stored and presented in the form of a map. Three basic types of spatial data models have evolved for storing geographic data digitally. These are referred to as:

Vector;

Raster;

Image.

The following diagram reflects the two primary spatial data encoding techniques. These are vector and raster. Image data utilizes techniques very similar to raster data, however typically lacks the internal formats required for analysis and modeling of the data. Images



reflect pictures or photographs of the landscape.

Fig: Representation of the real world and showing differences in how a vector and a raster GIS will represent this real world.

Vector Data Formats:

All spatial data models are approaches for storing the spatial location of geographic features in a database. Vector storage implies the use of vectors (directional lines) to represent a geographic feature. Vector data is characterized by the use of sequential points or vertices to define a linear segment. Each vertex consists of an X coordinate and a Y coordinate.

Vector lines are often referred to as arcs and consist of a string of vertices terminated by a node. A node is defined as a vertex that starts or ends an arc segment. Point features are defined by one coordinate pair, a vertex. Polygonal features are defined by a set of closed coordinate pairs. In vector representation, the storage of the vertices for each feature is important, as well as the connectivity between features, e.g. the sharing of common vertices where features connect.

Several different vector data models exist, however only two are commonly used in GIS data storage.

The most popular method of retaining spatial relationships among features is to explicitly record adjacency information in what is known as the topologic data model. Topology is a mathematical concept that has its basis in the principles of feature adjacency and connectivity.

The ***topologic data structure*** is often referred to as an intelligent data structure because spatial relationships between geographic features are easily derived when using them. Primarily for this reason the topologic model is the dominant vector data structure currently used in GIS technology. Many of the complex data analysis functions cannot effectively be undertaken without a topologic vector data structure.

The secondary vector data structure that is common among GIS software is the ***computer-aided drafting (CAD) data structure***. This structure consists of listing elements, not features, defined by strings of vertices, to define geographic features, e.g. points, lines, or areas. There is considerable redundancy with this data model since the boundary segment between two polygons can be stored twice, once for each feature. The CAD structure emerged from the development of computer graphics systems without specific considerations of processing geographic features. Accordingly, since features, e.g. polygons, are self-contained and independent, questions about the adjacency of features can be difficult to answer. The CAD vector model lacks the definition of spatial relationships between features that is defined by the topologic data model.

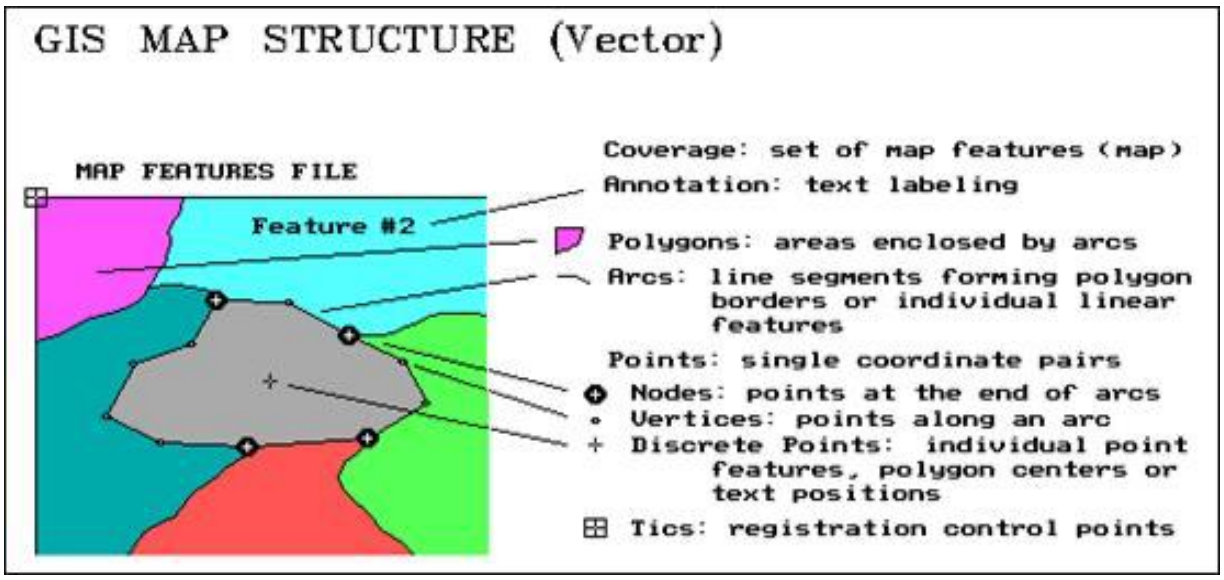


Fig: GIS MAP Structure - VECTOR systems (Adapted from Berry)

Raster Data Formats:

Raster data models incorporate the use of a grid-cell data structure where the geographic area is divided into cells identified by row and column. This data structure is commonly called raster. While the term raster implies a regularly spaced grid other tessellated data structures do exist in grid based GIS systems. In particular, the quadtree data structure has found some acceptance as an alternative raster data model.

The size of cells in a tessellated data structure is selected on the basis of the data accuracy and the resolution needed by the user. There is no explicit coding of geographic coordinates required since that is implicit in the layout of the cells. A raster data structure is in fact a matrix where any coordinate can be quickly calculated if the origin point is known, and the size of the grid cells is known. Since grid-cells can be handled as two-dimensional arrays in computer encoding many analytical operations are easy to program. This makes tessellated data structures a popular choice for many GIS software. Topology is not a relevant concept with tessellated structures since adjacency and connectivity are implicit in the location of a particular cell in the data matrix.

Several tessellated data structures exist, however only two are commonly used in GIS's. The most popular cell structure is the regularly spaced matrix or raster structure. This data structure involves a division of spatial data into regularly spaced cells. Each cell is of the same shape and size. Squares are most commonly utilized.

Since geographic data is rarely distinguished by regularly spaced shapes, cells must be classified as to the most common attribute for the cell. The problem of determining the proper resolution for a particular data layer can be a concern. If one selects too coarse a cell size then data may be overly generalized. If one selects too fine a cell size then too many cells may be created resulting in a large data volume, slower processing times, and a more cumbersome data set. As well, one can imply accuracy greater than that of the original data capture process and this may result in some erroneous results during analysis.

As well, since most data is captured in a vector format, e.g. digitizing, data must be converted to the raster data structure. This is called vector-raster conversion. Most GIS software allows the user to define the raster grid (cell) size for vector-raster conversion. It is imperative that the original scale, e.g. accuracy, of the data be known prior to conversion. The accuracy of the data, often referred to as the resolution, should determine the cell size of the output raster map during conversion.

Most raster based GIS software requires that the raster cell contain only a single discrete value. Accordingly, a data layer, e.g. forest inventory stands, may be broken down into a series of raster maps, each representing an attribute type, e.g. a species map, a height map, a density map, etc. These are often referred to as one attribute maps. This is in contrast to most conventional vector data models that maintain data as multiple attribute maps, e.g. forest inventory polygons linked to a database table containing all attributes as columns. This basic distinction of raster data storage provides the foundation for quantitative analysis techniques. This is often referred to as raster or map algebra. The use of raster data structures allow for sophisticated mathematical modelling processes while vector based systems are often constrained by the capabilities and language of a relational DBMS.

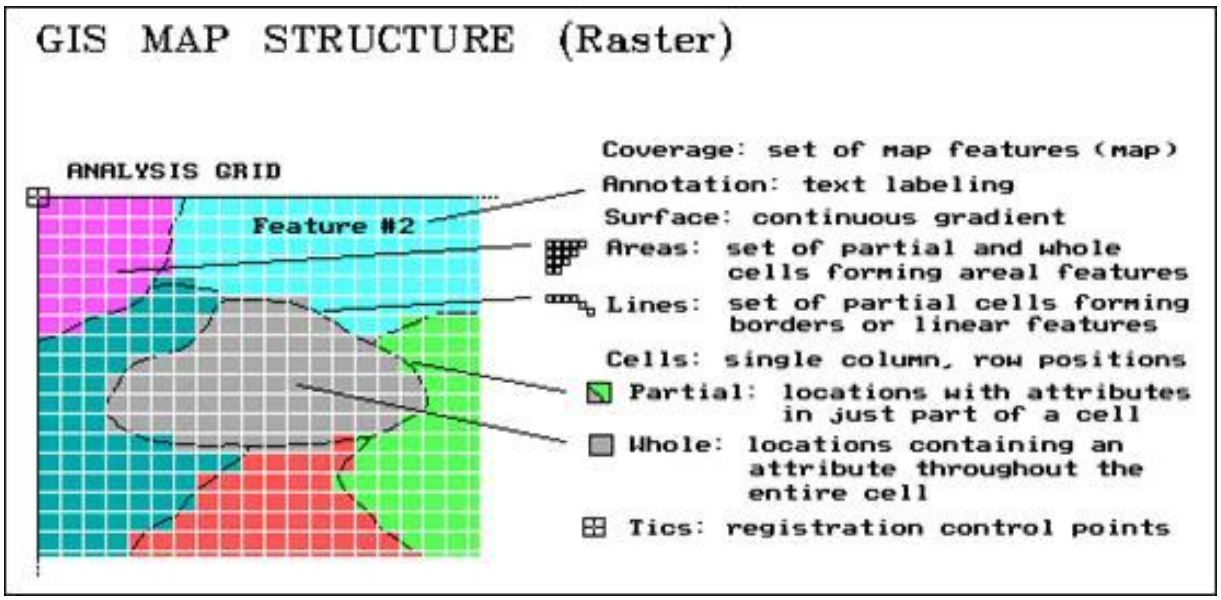


Fig: GIS MAP Structure - RASTER systems (Adapted from Berry)

This difference is the major distinguishing factor between vector and raster based GIS software. It is also important to understand that the selection of a particular data structure can provide advantages during the analysis stage. For example, the vector data model does not handle continuous data, e.g. elevation, very well while the raster data model is more ideally suited for this type of analysis. Accordingly, the raster structure does not handle linear data analysis, e.g. shortest path, very well while vector systems do. It is important for the user to understand that there are certain advantages and disadvantages to each data model.

The selection of a particular data model, vector or raster, is dependent on the source and type of data, as well as the intended use of the data. Certain analytical procedures require raster data while others are better suited to vector data.

Image Data:

Image data is most often used to represent graphic or pictorial data. The term image inherently reflects a graphic representation, and in the GIS world, differs significantly from raster data. Most often, image data is used to store remotely sensed imagery, e.g. satellite scenes or orthophotos, or ancillary graphics such as photographs, scanned plan documents, etc. Image data is typically used in GIS systems as background display data (if the image has been rectified and georeferenced); or as a graphic attribute. Remote sensing software makes use of image data for image classification and processing. Typically, this data must be converted into a raster format (and perhaps vector) to be used analytically with the GIS.

Image data is typically stored in a variety of de facto industry standard proprietary formats. These often reflect the most popular image processing systems. Other graphic image formats, such as TIFF, GIF, PCX, etc., are used to store ancillary image data. Most GIS software will read such formats and allow you to display this data.



Fig: Image data is most often used for remotely sensed imagery such as satellite imagery or digital orthophotos.

Vector and Raster - Advantages and Disadvantages:

There are several advantages and disadvantages for using either the vector or raster data model to store spatial data. These are summarized below.

Vector Data:

Advantages:

- Data can be represented at its original resolution and form without generalization.
- Graphic output is usually more aesthetically pleasing (traditional cartographic representation);
- Since most data, e.g. hard copy maps, is in vector form no data conversion is required.
- Accurate geographic location of data is maintained.
- Allows for efficient encoding of topology, and as a result more efficient operations that require topological information, e.g. proximity, network analysis.

Disadvantages:

- The location of each vertex needs to be stored explicitly.
- For effective analysis, vector data must be converted into a topological structure. This is often processing intensive and usually requires extensive data cleaning. As well, topology is static, and any updating or editing of the vector data requires re-building of the topology.
- Algorithms for manipulative and analysis functions are complex and may be processing intensive. Often, this inherently limits the functionality for large data sets, e.g. a large number of features.
- Continuous data, such as elevation data, is not effectively represented in vector form. Usually substantial data generalization or interpolation is required for these data layers.
- Spatial analysis and filtering within polygons is impossible

Raster Data:

Advantages:

- The geographic location of each cell is implied by its position in the cell matrix. Accordingly, other than an origin point, e.g. bottom left corner, no geographic coordinates are stored.
- Due to the nature of the data storage technique data analysis is usually easy to program and quick to perform.
- The inherent nature of raster maps, e.g. one attribute maps, is ideally suited for mathematical modeling and quantitative analysis.
- Discrete data, e.g. forestry stands, is accommodated equally well as continuous data, e.g. elevation data, and facilitates the integrating of the two data types.
- Grid-cell systems are very compatible with raster-based output devices, e.g. electrostatic plotters, graphic terminals.

Disadvantages:

- The cell size determines the resolution at which the data is represented.
- It is especially difficult to adequately represent linear features depending on the cell resolution. Accordingly, network linkages are difficult to establish.
- Processing of associated attribute data may be cumbersome if large amounts of data exists. Raster maps inherently reflect only one attribute or characteristic for an area.
- Since most input data is in vector form, data must undergo vector-to-raster conversion. Besides increased processing requirements this may introduce data integrity concerns due to generalization and choice of inappropriate cell size.

- Most output maps from grid-cell systems do not conform to high-quality cartographic needs.

It is often difficult to compare or rate GIS software that use different data models. Some personal computer (PC) packages utilize vector structures for data input, editing, and display but convert to raster structures for any analysis. Other more comprehensive GIS offerings provide both integrated raster and vector analysis techniques. They allow users to select the data structure appropriate for the analysis requirements. Integrated raster and vector processing capabilities are most desirable and provide the greatest flexibility for data manipulation and analysis.

Attribute Data Models:

A separate data model is used to store and maintain attribute data for GIS software. These data models may exist internally within the GIS software, or may be reflected in external commercial Database Management Software (DBMS). A variety of different data models exist for the storage and management of attribute data. The most common are:

- Tabular
- Hierarchial
- Network
- Relational
- Object Oriented

The tabular model is the manner in which most early GIS software packages stored their attribute data. The next three models are those most commonly implemented in database management systems (DBMS). The object oriented is newer but rapidly gaining in popularity for some applications. A brief review of each model is provided.

Tabular Model

The simple tabular model stores attribute data as sequential data files with fixed formats (or comma delimited for ASCII data), for the location of attribute values in a predefined record structure. This type of data model is outdated in the GIS arena. It lacks any method of checking data integrity, as well as being inefficient with respect to data storage, e.g. limited indexing capability for attributes or records, etc.

Hierarchical Model

The hierarchical database organizes data in a tree structure. Data is structured downward in a hierarchy of tables. Any level in the hierarchy can have unlimited children, but any child can have only one parent. Hierarchial DBMS have not gained any noticeable acceptance for use within GIS. They are oriented for data sets that are very stable, where primary relationships among the data change infrequently or never at all. Also, the limitation on the number of parents that an element may have is not always conducive to actual geographic phenomenon.

Network Model

The network database organizes data in a network or plex structure. Any column in a plex structure can be linked to any other. Like a tree structure, a plex structure can be described in terms of parents and children. This model allows for children to have more than one parent.

Network DBMS have not found much more acceptance in GIS than the hierarchical DBMS. They have the same flexibility limitations as hierarchical databases; however, the more powerful structure for representing data relationships allows a more realistic modelling of geographic phenomenon. However, network databases tend to become overly complex too easily. In this regard it is easy to lose control and understanding of the relationships between elements.

Relational Model

The relational database organizes data in tables. Each table, is identified by a unique table name, and is organized by rows and columns. Each column within a table also has a unique name. Columns store the values for a specific attribute, e.g. cover group, tree height. Rows represent one record in the table. In a GIS each row is usually linked to a separate spatial feature, e.g. a forestry stand. Accordingly, each row would be comprised of several columns, each column containing a specific value for that geographic feature. The following figure presents a sample table for forest inventory features. This table has 4 rows and 5 columns. The forest stand number would be the label for the spatial feature as well as the primary key for the database table. This serves as the linkage between the spatial definition of the feature and the attribute data for the feature.

Unique Stand Number	Dominant Cover Group	Avg. Tree Height	Stand Site Index	Stand Age
1	DEC	3	G	100
2	DEC-CON	4	M	80
3	DEC-CON	4	M	60
4	CON	4	G	120

Data is often stored in several tables. Tables can be joined or referenced to each other by common columns (relational fields). Usually the common column is an identification number for a selected geographic feature, e.g. a forestry stand polygon number. This identification number acts as the primary key for the table. The ability to join tables through use of a common column is the essence of the relational model. Such relational joins are usually ad hoc in nature and form the basis of for querying in a relational GIS product. Unlike the other previously discussed database types, relationships are implicit in the character of the data as opposed to explicit characteristics of the database set up.

The relational database model is the most widely accepted for managing the attributes of geographic data.

There are many different designs of DBMSs, but in GIS the relational design has been the most useful. In the relational design, data are stored conceptually as a collection of tables. Common fields in different tables are used to link them together. This surprisingly simple design has been so widely used primarily because of its flexibility and very wide deployment in applications both within and without GIS.

In fact, most GIS software provides an internal relational data model, as well as support for commercial off-the-shelf (COTS) relational DBMS'. COTS DBMS' are referred to as external DBMS'. This approach supports both users with small data sets, where an internal data model is sufficient, and customers with larger data sets who utilize a DBMS

for other corporate data storage requirements. With an external DBMS the GIS software can simply connect to the database, and the user can make use of the inherent capabilities of the DBMS. External DBMS' tend to have much more extensive querying and data integrity capabilities than the GIS' internal relational model. The emergence and use of the external DBMS is a trend that has resulted in the proliferation of GIS technology into more traditional data processing environments.

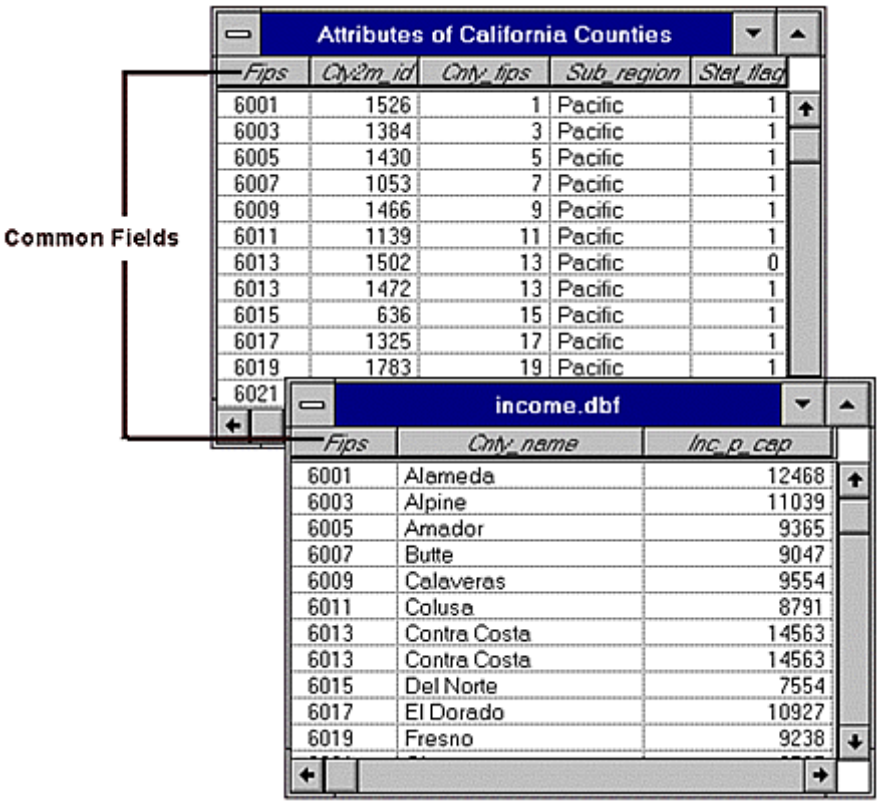


Fig: In the relational design, data are stored conceptually as a collection of tables. Common fields in different tables are used to link them together.

The relational DBMS is attractive because of its:

- simplicity in organization and data modelling.
- flexibility - data can be manipulated in an ad hoc manner by joining tables.
- efficiency of storage - by the proper design of data tables redundant data can be minimized; and
- the non-procedural nature - queries on a relational database do not need to take into account the internal organization of the data.

The following diagram illustrates the basic linkage between a vector spatial data (topologic model) and attributes maintained in a relational database file.

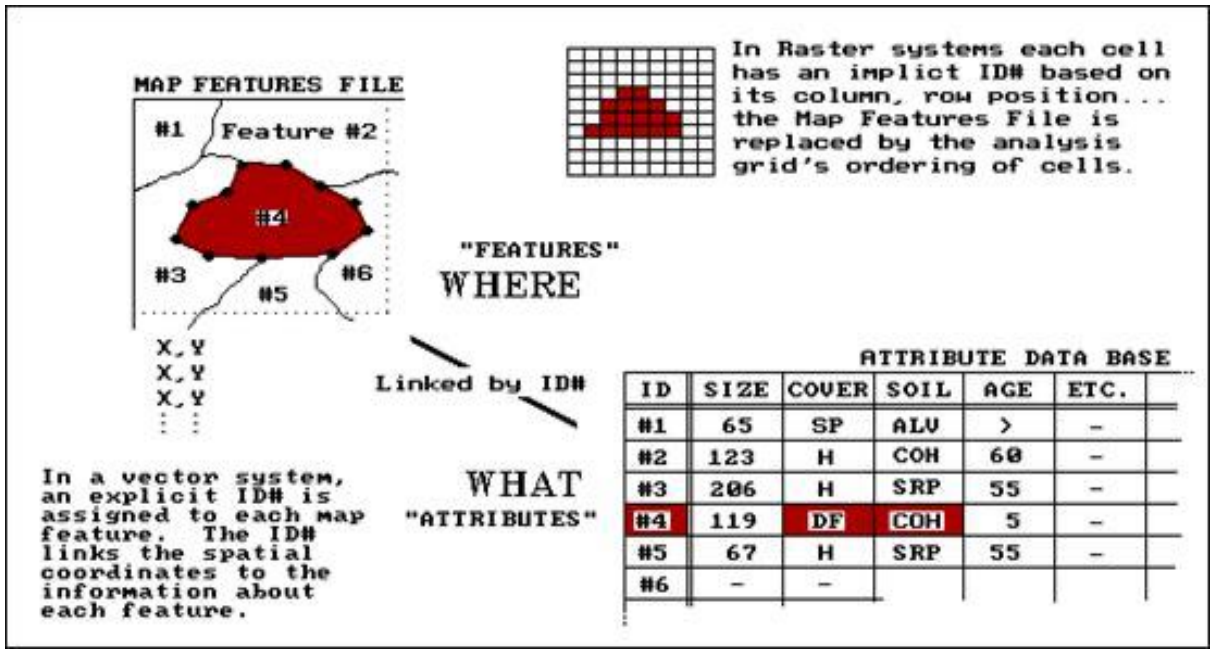


Fig: Basic linkages between a vector spatial data (topologic model) and attributes maintained in a relational database file (From Berry)

Object-Oriented Model

The object-oriented database model manages data through objects. An object is a collection of data elements and operations that together are considered a single entity. The object-oriented database is a relatively new model. This approach has the attraction that querying is very natural, as features can be bundled together with attributes at the database administrator's discretion. To date, only a few GIS packages are promoting the use of this attribute data model. However, initial impressions indicate that this approach may hold many operational benefits with respect to geographic data processing. Fulfilment of this promise with a commercial GIS product remains to be seen.

Spatial Data Relationships:

The nature of spatial data relationships are important to understand within the context of GIS. In particular, the relationship between geographic features is a complex problem in which we are far from understanding in its entirety. This is of concern since the primary role of GIS is the manipulation and analysis of large quantities of spatial data. To date, the accepted theoretical solution is to topologically structure spatial data.

It is believed that a topologic data model best reflects the geography of the real world and provides an effective mathematical foundation for encoding spatial relationships, providing a data model for manipulating and analyzing vector based data.

Most GIS software segregate spatial and attribute data into separate data management systems. Most frequently, the topological or raster structure is used to store the spatial data, while the relational database structure is used to store the attribute data. Data from both structures are linked together for use through unique identification numbers, e.g. feature labels and DBMS primary keys. This coupling of spatial features with an attribute record is usually maintained by an internal number assigned by the GIS software. A label is required so the user can load the appropriate attribute record for a given geographic feature. Most often a single attribute record is automatically created by the GIS software once a clean topological structure is properly generated. This attribute record normally contains the internal number for the feature, the user's label identifier, the area of the feature, and the perimeter of the feature. Linear features have the length of the feature defined instead of the area.

Topology:

The topologic model is often confusing to initial users of GIS. Topology is a mathematical approach that allows us to structure data based on the principles of feature adjacency and feature connectivity. It is in fact the mathematical method used to define spatial relationships. Without a topologic data structure in a vector based GIS most data manipulation and analysis functions would not be practical or feasible.

The most common topological data structure is the arc/node data model. This model contains two basic entities, the arc and the node. The arc is a series of points, joined by straight line segments, that start and end at a node. The node is an intersection point where two or more arcs meet. Nodes also occur at the end of a dangling arc, e.g. an arc that does not connect to another arc such as a dead end street. Isolated nodes, not connected to arcs represent point features. A polygon feature is comprised of a closed chain of arcs.

In GIS software the topological definition is commonly stored in a proprietary format. However, most software offerings record the topological definition in three tables. These tables are analogous to relational tables. The three tables represent the different types of features, e.g. point, line, area. A fourth table containing the coordinates is also utilized. The node table stores information about the node and the arcs that are connected to it. The arc table contains topological information about the arcs. This includes the start and end node, and the polygon to the left and right that the arc is an element of. The polygon table defines the arcs that make up each polygon. While arc, node, and polygon terminology is used by most GIS vendors, some also introduce terms such as edges and faces to define arcs and polygons. This is merely the use of different words to define topological definitions. Do not be confused by this.

Since most input data does not exist in a topological data structure, topology must be built with the GIS software. Depending on the data set this can be an CPU intensive and time consuming procedure. This building process involves the creation of the topological tables and the definition of the arc, node, and polygon entities. To properly define the topology there are specific requirements with respect to graphic elements, e.g. no duplicate lines, no gaps in arcs that define polygon features, etc

The topological model is utilized because it effectively models the relationship of spatial entities. Accordingly, it is well suited for operations such as contiguity and connectivity analyses. Contiguity involves the evaluation of feature adjacency, e.g. features that touch

one another, and proximity, e.g. features that are near one another. The primary advantage of the topological model is that spatial analysis can be done without using the coordinate data. Many operations can be done largely, if not entirely, by using the topological definition alone. This is a significant advantage over the CAD or spaghetti vector data structure that requires the derivation of spatial relationships from the coordinate data before analysis can be undertaken.

The major disadvantage of the topological data model is its static nature. It can be a time consuming process to properly define the topology depending on the size and complexity of the data set. For example, 2,000 forest stand polygons will require considerably longer to build the topology that 2,000 municipal lot boundaries. This is due to the inherent complexity of the features, e.g. lots tend to be rectangular while forest stands are often long and sinuous. This can be a consideration when evaluating the topological building capabilities of GIS software. The static nature of the topological model also implies that every time some editing has occurred, e.g. forest stand boundaries are changed to reflect harvesting or burns, the topology must be rebuilt. The integrity of the topological structure and the DBMS tables containing the attribute data can be a concern here. This is often referred to as referential integrity. While topology is the mechanism to ensure integrity with spatial data, referential integrity is the concept of ensuring integrity for both linked topological data and attribute data.

Data Sources:

This part reviews different sources, formats, and input techniques for GIS data. The focus is on reviewing different data input techniques for spatial data. This chapter also describes data input errors, spatial and attribute, and reviews typical procedures to correct input errors. This chapter will be of most interest to technical staff and GIS operators.

- Sources of Data
- Data input techniques
- Data editing and quality assurance

Sources of Data:

As previously identified, two types of data are input into a GIS, spatial and attribute. The data input process is the operation of encoding both types of data into the GIS database formats.

The creation of a clean digital database is the most important and time consuming task upon which the usefulness of the GIS depends. The establishment and maintenance of a robust spatial database is the cornerstone of a successful GIS implementation.

As well, the digital data is the most expensive part of the GIS. Yet often, not enough attention is given to the quality of the data or the processes by which they are prepared for automation.

The general consensus among the GIS community is that 60 to 80 % of the cost incurred during implementation of GIS technology lies in data acquisition, data compilation and database development.

A wide variety of data sources exist for both spatial and attribute data. The most common general sources for spatial data are:

- Hard copy maps;
- Aerial photographs;
- Remotely- sensed imagery;
- Point data samples from surveys; and
- Existing digital data files.

Existing hard copy maps, e.g. sometimes referred to as analogue maps, provide the most popular source for any GIS project.

Potential users should be aware that while there are many private sector firms specializing in providing digital data, federal, provincial and state government agencies are an excellent source of data. Because of the large costs associated with data capture and input, government departments are often the only agencies with financial resources and manpower funding to invest in data compilation. British Columbia and Alberta government agencies are good examples. Both provincial governments have defined and implemented province wide coverage of digital base map data at varying map scales, e.g. 1:20,000 and 1:250,000. As well, the provincial forestry agencies also provide thematic forest inventory data in digital format. Federal agencies are also often a good source for base map information. An inherent advantage of digital data from government agencies is its cost. It is typically inexpensive. However, this is often offset by the data's accuracy and quality. Thematic coverages are often not up to date. However, it is important to note that specific characteristics of government data varies greatly across North America.

Attribute data has an even wider variety of data sources. Any textual or tabular data than can be referenced to a geographic feature, e.g. a point, line, or area, can be input into a GIS. Attribute data is usually input by manual keying or via a bulk loading utility of the DBMS software. ASCII format is a de facto standard for the transfer and conversion of attribute information.

The following figure describes the basic data types that are used and created by a GIS.

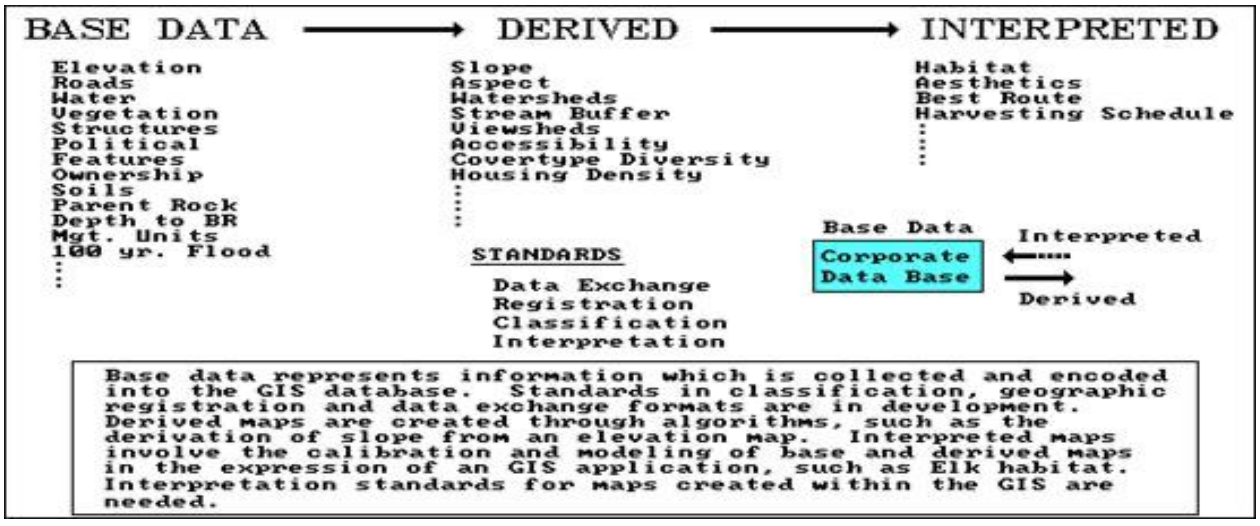


Fig: The basic data types that are used and created by a GIS (after Berry).

Data Input Techniques:

Since the input of attribute data is usually quite simple, the discussion of data input techniques will be limited to spatial data only. There is no single method of entering the spatial data into a GIS. Rather, there are several, mutually compatible methods that can be used singly or in combination.

The choice of data input method is governed largely by the application, the available budget, and the type and the complexity of data being input.

There are at least four basic procedures for inputting spatial data into a GIS. These are:

- Manual digitising;
- Automatic scanning;
- Entry of coordinates using coordinate geometry; and the
- Conversion of existing digital data

Digitizing:

While considerable work has been done with newer technologies, the overwhelming majority of GIS spatial data entry is done by manual digitizing. A digitizer is an electronic device consisting of a table upon which the map or drawing is placed. The user traces the spatial features with a hand-held magnetic pen, often called a mouse or cursor. While tracing the features the coordinates of selected points, e.g. vertices, are sent to the computer and stored. All points that are recorded are registered against positional control points, usually the map corners, that are keyed in by the user at the beginning of the digitizing session. The coordinates are recorded in a user defined coordinate system or map projection. Latitude and longitude and UTM is most often used. The ability to adjust or transform data during digitizing from one projection to another is a desirable function of the GIS software. Numerous functional techniques exist to aid the operator in the digitizing process.

Digitizing can be done in a point mode, where single points are recorded one at a time, or in a stream mode, where a point is collected on regular intervals of time or distance, measured by an X and Y movement, e.g. every 3 metres. Digitizing can also be done blindly or with a graphics terminal. Blind digitizing infers that the graphic result is not immediately viewable to the person digitizing. Most systems display the digitized linework as it is being digitized on an accompanying graphics terminal.

Most GIS's use a spaghetti mode of digitizing. This allows the user to simply digitize lines by indicating a start point and an end point. Data can be captured in point or stream mode. However, some systems do allow the user to capture the data in an arc/node topological data structure. The arc/node data structure requires that the digitizer identify nodes.

Data capture in an arc/node approach helps to build a topologic data structure immediately. This lessens the amount of post processing required to clean and build the topological definitions. However, most often digitizing with an arc/node approach does not negate the requirement for editing and cleaning of the digitized linework before a complete topological structure can be obtained.

The building of topology is primarily a post-digitizing process that is commonly executed in batch mode after data has been cleaned. To date, only a few commercial vector GIS software offerings have successfully exhibited the capability to build topology interactively while the user digitizes.

Manual digitizing has many advantages. These include:

- Low capital cost, e.g. digitizing tables are cheap;
- Low cost of labour;
- Flexibility and adaptability to different data types and sources;
- Easily taught in a short amount of time - an easily mastered skill
- Generally the quality of data is high;
- Digitizing devices are very reliable and most often offer a greater precision that the data warrants; and
- Ability to easily register and update existing data.

For raster based GIS software data is still commonly digitized in a vector format and converted to a raster structure after the building of a clean topological structure. The procedure usually differs minimally from vector based software digitizing, other than some raster systems allow the user to define the resolution size of the grid-cell. Conversion to the raster structure may occur on-the-fly or afterwards as a separate conversion process.

Automatic Scanning:

A variety of scanning devices exist for the automatic capture of spatial data. While several different technical approaches exist in scanning technology, all have the advantage of being able to capture spatial features from a map at a rapid rate of speed. However, as of yet, scanning has not proven to be a viable alternative for most GIS implementation. Scanners are generally expensive to acquire and operate. As well, most scanning devices have limitations with respect to the capture of selected features, e.g. text and symbol recognition. Experience has shown that most scanned data requires a substantial amount of manual editing to create a clean data layer. Given these basic constraints some other practical limitations of scanners should be identified. These include :

- hard copy maps are often unable to be removed to where a scanning device is available, e.g. most companies or agencies cannot afford their own scanning device and therefore must send their maps to a private firm for scanning;
- hard copy data may not be in a form that is viable for effective scanning, e.g. maps are of poor quality, or are in poor condition;
- geographic features may be too few on a single map to make it practical, cost-justifiable, to scan;
- Often on busy maps a scanner may be unable to distinguish the features to be captured from the surrounding graphic information, e.g. dense contours with labels;

- with raster scanning there it is difficult to read unique labels (text) for a geographic feature effectively; and

- scanning is much more expensive than manual digitizing, considering all the cost/performance issues.

Consensus within the GIS community indicates that scanners work best when the information on a map is kept very clean, very simple, and uncluttered with graphic symbology.

The sheer cost of scanning usually eliminates the possibility of using scanning methods for data capture in most GIS implementations. Large data capture shops and government agencies are those most likely to be using scanning technology.

Currently, general consensus is that the quality of data captured from scanning devices is not substantial enough to justify the cost of using scanning technology. However, major breakthroughs are being made in the field, with scanning techniques and with capabilities to automatically clean and prepare scanned data for topological encoding. These include a variety of line following and text recognition techniques. Users should be aware that this technology has great potential in the years to come, particularly for larger GIS installations.

Coordinate Geometry

A third technique for the input of spatial data involves the calculation and entry of coordinates using coordinate geometry (COGO) procedures. This involves entering, from survey data, the explicit measurement of features from some known monument. This input technique is obviously very costly and labour intensive. In fact, it is rarely used for natural resource applications in GIS. This method is useful for creating very precise cartographic definitions of property, and accordingly is more appropriate for land records management at the cadastral or municipal scale.

Conversion of Existing Digital Data

A fourth technique that is becoming increasingly popular for data input is the conversion of existing digital data. A variety of spatial data, including digital maps, are openly available from a wide range of government and private sources. The most common digital data to be used in a GIS is data from CAD systems. A number of data conversion programs exist, mostly from GIS software vendors, to transform data from CAD formats to a raster or topological GIS data format. Several ad hoc standards for data exchange have been established in the market place. These are supplemented by a number of government distribution formats that have been developed. Given the wide variety of data formats that exist, most GIS vendors have developed and provide data exchange/conversion software to go from their format to those considered common in the market place.

Most GIS software vendors also provide an ASCII data exchange format specific to their product, and a programming subroutine library that will allow users to write their own data conversion routines to fulfil their own specific needs. As digital data becomes more readily available this capability becomes a necessity for any GIS. Data conversion from existing digital data is not a problem for most technical persons in the GIS field. However, for smaller GIS installations who have limited access to a GIS analyst this can

be a major stumbling block in getting a GIS operational. Government agencies are usually a good source for technical information on data conversion requirements.

Some of the data formats common to the GIS marketplace are listed below. Please note that most formats are only utilized for graphic data. Attribute data is usually handled as ASCII text files. Vendor names are supplied where appropriate.

IGDS - Interactive Graphics Design Software (Intergraph / Microstation)	This binary format is a standard in the turnkey CAD market and has become a de facto standard in Canada's mapping industry. It is a proprietary format, however most GIS software vendors provide DGN translators.
DLG - Digital Line Graph (US Geological Survey)	This ASCII format is used by the USGS as a distribution standard and consequently is well utilized in the United States. It is not used very much in Canada even though most software vendors provide two way conversion to DLG.
DXF - Drawing Exchange Format (Autocad)	This ASCII format is used primarily to convert to/from the Autocad drawing format and is a standard in the engineering discipline. Most GIS software vendors provide a DXF translator.
GENERATE - ARC/INFO Graphic Exchange Format	A generic ASCII format for spatial data used by the ARC/INFO software to accommodate generic spatial data.
EXPORT - ARC/INFO Export Format	An exchange format that includes both graphic and attribute data. This format is intended for transferring ARC/INFO data from one hardware platform, or site, to another. It is also often used for archiving. ARC/INFO data. This is not a published data format, however some GIS and desktop mapping vendors provide translators. EXPORT format can come in either uncompressed, partially compressed, or fully compressed format

A wide variety of other vendor specific data formats exist within the mapping and GIS industry. In particular, most GIS software vendors have their own proprietary formats. However, almost all provide data conversion to/from the above formats. As well, most GIS software vendors will develop data conversion programs dependant on specific requests by customers. Potential purchasers of commercial GIS packages should determine and clearly identify their data conversion needs, prior to purchase, to the software vendor.

Data Editing and Quality Assurance:

Data editing and verification is in response to the errors that arise during the encoding of spatial and non-spatial data. The editing of spatial data is a time consuming, interactive process that can take as long, if not longer, than the data input process itself.

Several kinds of errors can occur during data input. They can be classified as:

Incompleteness of the spatial data: This includes missing points, line segments, and/or polygons.

Locational placement errors of spatial data: These types of errors usually are the result of careless digitizing or poor quality of the original data source.

Distortion of the spatial data: This kind of error is usually caused by base maps that are not scale-correct over the whole image, e.g. aerial photographs, or from material stretch, e.g. paper documents.

Incorrect linkages between spatial and attribute data: This type of error is commonly the result of incorrect unique identifiers (labels) being assigned during manual key in or digitizing. This may involve the assigning of an entirely wrong label to a feature, or more than one label being assigned to a feature.

Attribute data is wrong or incomplete: Often the attribute data does not match exactly with the spatial data. This is because they are frequently from independent sources and often different time periods. Missing data records or too many data records are the most common problems.

The identification of errors in spatial and attribute data is often difficult. Most spatial errors become evident during the topological building process. The use of check plots to clearly determine where spatial errors exist is a common practice. Most topological building functions in GIS software clearly identify the geographic location of the error and indicate the nature of the problem. Comprehensive GIS software allows users to graphically walk through and edit the spatial errors. Others merely identify the type and coordinates of the error. Since this is often a labour intensive and time consuming process, users should consider the error correction capabilities very important during the evaluation of GIS software offerings.

Spatial Data Errors:

A variety of common data problems occur in converting data into a topological structure. These stem from the original quality of the source data and the characteristics of the data capture process. Usually data is input by digitizing. Digitizing allows a user to trace spatial data from a hard copy product, e.g. a map, and have it recorded by the computer software. Most GIS software has utilities to clean the data and build a topologic structure. If the data is unclean to start with, for whatever reason, the cleaning process can be very lengthy. Interactive editing of data is a distinct reality in the data input process.

Experience indicates that in the course of any GIS project 60 to 80 % of the time required to complete the project is involved in the input, cleaning, linking, and verification of the data.

The most common problems that occur in converting data into a topological structure include:

- slivers and gaps in the line work;
- dead ends, e.g. also called dangling arcs, resulting from overshoots and undershoots in the line work; and
- bow ties or weird polygons from inappropriate closing of connecting features.

Of course, topological errors only exist with linear and areal features. They become most evident with polygonal features. Slivers are the most common problem when cleaning data. Slivers frequently occur when coincident boundaries are digitized separately, e.g. once each for adjacent forest stands, once for a lake and once for the stand boundary, or after polygon overlay. Slivers often appear when combining data from different sources, e.g. forest inventory, soils, and hydrography. It is advisable to digitize data layers with respect to an existing data layer, e.g. hydrography, rather than attempting to match data layers later. A proper plan and definition of priorities for inputting data layers will save many hours of interactive editing and cleaning.

Dead ends usually occur when data has been digitized in a spaghetti mode, or without snapping to existing nodes. Most GIS software will clean up undershoots and overshoots based on a user defined tolerance, e.g. distance. The definition of an inappropriate distance often leads to the formation of bow ties or weird polygons during topological building. Tolerances that are too large will force arcs to snap one another that should not be connected. The result is small polygons called bow ties. The definition of a proper tolerance for cleaning requires an understanding of the scale and accuracy of the data set.

The other problem that commonly occurs when building a topologic data structure is duplicate lines. These usually occur when data has been digitized or converted from a CAD system. The lack of topology in these type of drafting systems permits the inadvertent creation of elements that are exactly duplicate. However, most GIS packages afford automatic elimination of duplicate elements during the topological building process. Accordingly, it may not be a concern with vector based GIS software. Users should be aware of the duplicate element that retraces itself, e.g. a three vertice line where the first point is also the last point. Some GIS packages do not identify these feature inconsistencies and will build such a feature as a valid polygon. This is because the topological definition is mathematically correct, however it is not geographically correct. Most GIS software will provide the capability to eliminate bow ties and slivers by means of a feature elimination command based on area, e.g. polygons less than 100 square metres. The ability to define custom topological error scenarios and provide for semi-automated correction is a desirable capability for GIS software.

The adjoining figure illustrates some typical errors described above. Can you spot them ? They include undershoots, overshoots, bow ties, and slivers. Most bow ties occur when inappropriate tolerances are used during the automated cleaning of data that contains many overshoots. This particular set of spatial data is a prime candidate for numerous bow tie polygons.

Attribute Data Errors

The identification of attribute data errors is usually not as simple as spatial errors. This is especially true if these errors are attributed to the quality or reliability of the data. Errors

as such usually do not surface until later on in the GIS processing. Solutions to these type of problems are much more complex and often do not exist entirely. It is much more difficult to spot errors in attribute data when the values are syntactically good, but incorrect.

Simple errors of linkage, e.g. missing or duplicate records, become evident during the linking operation between spatial and attribute data. Again, most GIS software contains functions that check for and clearly identify problems of linkage during attempted operations. This is also an area of consideration when evaluating GIS software.

Data Verification

Six clear steps stand out in the data editing and verification process for spatial data. These are:

Visual review. This is usually by check plotting

Cleanup of lines and junctions. This process is usually done by software first and interactive editing second.

Weeding of excess coordinates. This process involves the removal of redundant vertices by the software for linear and/or polygonal features.

Correction for distortion and wraping. Most GIS software has functions for scale correction and rubber sheeting. However, the distinct rubber sheet algorithm used will vary depending on the spatial data model, vector or raster, employed by the GIS. Some raster techniques may be more intensive than vector based algorithms.

Construction of polygons. Since the majority of data used in GIS is polygonal, the construction of polygon features from lines/arcs is necessary. Usually this is done in conjunction with the topological building process.

The addition of Unique identifiers or labels. Often this process is manual. However, some systems do provide the capability to automatically build labels for a data layer.

These data verification steps occur after the data input stage and prior to or during the linkage of the spatial data to the attributes. Data verification ensures the integrity between the spatial and attribute data. Verification should include some brief querying of attributes and cross checking against known values.

Data Organization and Storage:

This part reviews the approaches for organizing and maintaining data in a GIS. The focus is on reviewing different techniques for storing spatial data. A brief review of data querying approaches for attribute data is also provided.

- Organising data for analysis
- Editing and updating of data

The second necessary component for a GIS is the data storage and retrieval subsystem. This subsystem organizes the data, both spatial and attribute, in a form which permits it to be quickly retrieved for updating, querying, and analysis. Most GIS software utilizes proprietary software for their spatial editing and retrieval system, and a database management system (DBMS) for their attribute storage. Typically, an internal data model is used to store primary attribute data associated with the topological definition of the

spatial data. Most often these internal database tables contain primary columns such as area, perimeter, length, and internal feature id number. Often thematic attribute data is maintained in an external DBMS that is linked to the spatial data via the internal database table.

Organizing Data for Analysis:

Most GIS software organizes spatial data in a thematic approach that categorizes data in vertical layers. The definition of layers is fully dependent on the organization's requirements. Typical layers used in natural resource management agencies or companies include forest cover, soil classification, elevation, road network (access), ecological areas, hydrology, etc.

Spatial data layers are commonly input one at a time, e.g. forest cover. Accordingly, attribute data is entered one layer at a time. Depending on the attribute data model used by the data storage subsystem data must be organized in a format that will facilitate the manipulation and analysis tasks that will be required. Most often, the spatial and attribute data may be entered at different times and linked together later. However, this is fully dependent on the source of data.

The clear identification of the requirements for any GIS project is necessary before any data input procedures, and/or layer definitions, should occur.

It is mandatory that GIS users fully understand their needs before undertaking a GIS project.

Experience has shown that a less than complete understanding of the needs and processing tasks required for a specific project, greatly increases the time required to complete the project, and ultimately affects the quality and reliability of the derived GIS product(s).

Spatial Data Layers - Vertical Data Organization:

In most GIS software data is organized in themes as data layers. This approach allows data to be input as separate themes and overlaid based on analysis requirements. This can conceptualized as vertical layering the characteristics of the earth's surface. The overlay concept is so natural to cartographers and natural resource specialists that it has been built into the design of most CAD vector systems as well. The overlay/layer approach used in CAD systems is used to separate major classes of spatial features. This concept is also used to logically order data in most GIS software. The terminology may differ between GIS software, but the approach is the same. A variety of terms are used to define data layers in commercial GIS software. These include themes, coverages, layers, levels, objects, and feature classes. Data layer and theme are the most common and the least proprietary to any particular GIS software and accordingly, as used throughout the book.

In any GIS project a variety of data layers will be required. These must be identified before the project is started and a priority given to the input or digitizing of the spatial data layers. This is mandatory, as often one data layer contains features that are coincident with another, e.g. lakes can be used to define polygons within the forest inventory data layer. Data layers are commonly defined based on the needs of the user and the availability of data. They are completely user definable.

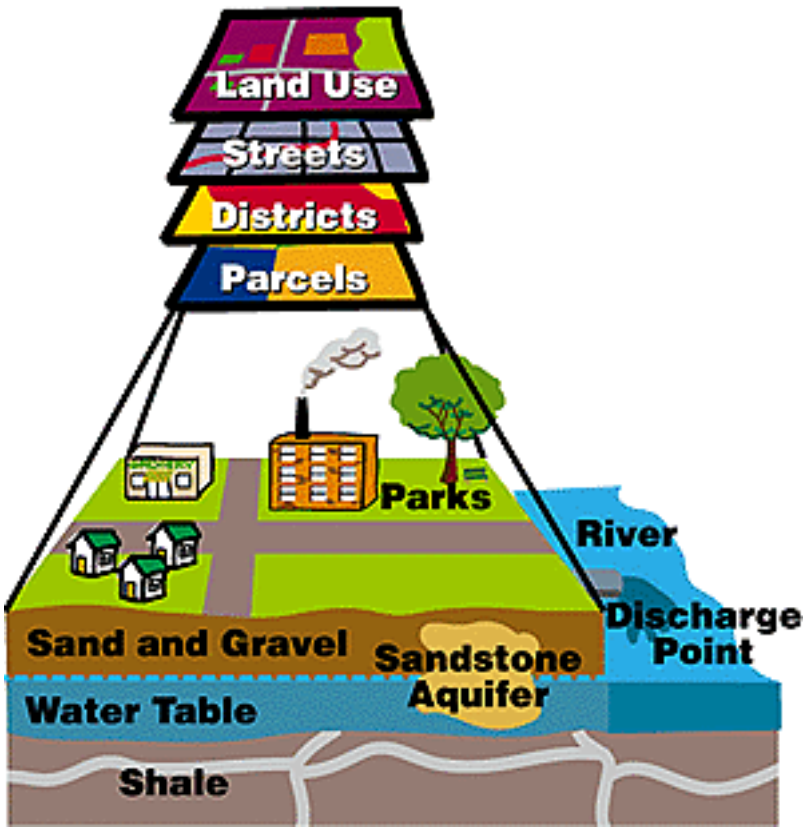


Fig: The definition of data layers is fully dependent on the area of interest and the priority needs of the GIS. Layer definitions can vary greatly depending on the intended needs of the GIS.

When considering the physical requirements of the GIS software it is important to understand that two types of data are required for each layer, attribute and spatial data. Commonly, data layers are input into the GIS one layer at a time. As well, often a data layer is completely loaded, e.g. graphic conversion, editing, topological building, attribute conversion, linking, and verification, before the next data layer is started. Because there are several steps involved in completely loading a data layer it can become very confusing if many layers are loaded at once.

The proper identification of layers prior to starting data input is critical. The identification of data layers is often achieved through a user needs analysis. The user needs analysis performs several functions including:

- Identifying the users;
- Educating users with respect to GIS needs;
- Identifying information products;
- Identifying data requirements for information products;
- priorizing data requirements and products; and
- determining GIS functional requirements.

Often a user needs assessment will include a review of existing operations, e.g. sometimes called a situational assessment, and a cost-benefit analysis. The cost-benefit process is well established in conventional data processing and serves as the mechanism to justify acquisition of hardware and software. It defines and compares costs against potential benefits. Most institutions will require this step before a GIS acquisition can be undertaken.

Most GIS projects integrate data layers to create derived themes or layers that represent the result of some calculation or geographic model, e.g. forest merchantability, land use suitability, etc. Derived data layers are completely dependant on the aim of the project.

Each data layer would be input individually and topologically integrated to create combined data layers. Based on the data model, e.g. vector or raster, and the topological structure, selected data analysis functions could be undertaken. It is important to note that in vector based GIS software the topological structure defined can only be traversed by means of unique labels to every feature.

Spatial Indexing - Horizontal Data Organization

The proprietary organization of data layers in a horizontal fashion within a GIS is known as spatial indexing. Spatial indexing is the method utilized by the software to store and retrieve spatial data. A variety of different strategies exist for speeding up the spatial feature retrieval process within a GIS software product. Most involve the partitioning of the geographic area into manageable subsets or tiles. These tiles are then indexed mathematically, e.g. by quadtrees, by R (rectangle) trees, to allow for quick searching and retrieval when querying is initiated by a user. Spatial indexing is analygous to the definition of map sheets, except that specific indexing techniques are used to access data across map sheet (tile) boundaries. This is done simply to improve query performance for large data sets that span multiple map sheets, and to ensure data integrity across map sheet boundaries.

The method and process of spatial indexing is usually transparent to the user. However, it becomes very important especially when large data sets are utilized. The notion of spatial indexing has become increasingly important in the design of GIS software over the last few years, as larger scale applications have been initiated using GIS technology. Users have found that often the response time in querying very large data sets is unacceptably slow. GIS software vendors have responded by developing sophisticated algorithms to index and retrieve spatial data. It is important to note that raster systems, by the nature of their data structure, do not typically require a spatial indexing method. The raster approach imposes regular, readily addressable partitions on the data universe intrinsically with its data structure. Accordingly, spatial indexing is usually not required. However, the more sophisticated vector GIS does require a method to quickly retrieve spatial objects.

The horizontal indexing of spatial data within GIS software involves several issues. These concern the extent of the spatial indexing approach. They include:

- the use of a librarian subsystem to organize data for users;
- the requirement for a formal definition of layers;
- the need for feature coding within themes or layers; and

- requirements to maintain data integrity through transaction control, e.g. the locking of selected spatial tiles (or features) when editing is being undertaken by a permitted user.

While all these issues need not be satisfied for spatial indexing to occur, they are important aspects users should consider when evaluating GIS software.

While the spatial indexing method is usually not the selling point of any GIS, users should consider these requirements, especially if very large data sets, e.g. 10,000 + polygons, are to be the norm in their applications, and a vector data model is to be employed.

Editing and Updating Of Data

Perhaps the primary function in the data storage and retrieval subsystem involves the editing and updating of data. Frequently, the following data editing capabilities are required:

- Interactive editing of spatial data;
- Interactive editing of attribute data;
- the ability to add, manipulate, modify, and delete both spatial features and attributes (independently or simultaneously) ; and the
- ability to edit selected features in a batch processing mode.

Updating involves more than the simple editing of features. Updating implies the resurvey and processing of new information. The updating function is of great importance during any GIS project. The life span of most digital data can range anywhere from 1 to 10 years. Commonly, digital data is valid for 5 to 10 years. The lengthy time span is due to the intensive task of data capture and input. However, often periodic data updates are required. These frequently involve an increased accuracy and/or detail of the data layer. Changes in classification standards and procedures may necessitate such updates. Updates to a forest cover data layer to reflect changes from a forest fire burn or a harvest cut are typical examples.

Many times data updates are required based on the results of a derived GIS product. The generation of a derived product may identify blatant errors or inappropriate classes for a particular layer. When this occurs updating of the data is required. In this situation the GIS operator usually has some previous experience or knowledge of the study area.

Commonly the data update process is a result of a physical change in the geographic landscape. Forest fires are a prime example. With this type of update new features are usually required for the data layer, e.g. burn polygons. As well, existing features are altered, e.g. forest stands that were affected. There is a strong requirement for a historical record keeping capability with this type of update process. Users should be aware of this requirement and design their database organization to accommodate such needs. Depending on the particular GIS, the update process may involve some data manipulation and analysis functions.

Data retrieval and querying

The ability to query and retrieve data based on some user defined criteria is a necessary feature of the data storage and retrieval subsystem.

Data retrieval involves the capability to easily select data for graphic or attribute editing, updating, querying, analysis and/or display.

The ability to retrieve data is based on the unique structure of the DBMS and command interfaces are commonly provided with the software. Most GIS software also provides a programming subroutine library, or macro language, so the user can write their own specific data retrieval routines if required.

Querying is the capability to retrieve data, usually a data subset, based on some user defined formula. These data subsets are often referred to as logical views. Often the querying is closely linked to the data manipulation and analysis subsystem. Many GIS software offerings have attempted to standardize their querying capability by use of a Standard Query Language (SQL). This is especially true with systems that make use of an external relational DBMS. Through the use of SQL, GIS software can interface to a variety of different DBMS packages. This approach provides the user with the flexibility to select their own DBMS. This has direct implications if the organization has an existing DBMS that is being used for to satisfy other business requirements. Often it is desirable for the same DBMS to be utilized in the GIS applications. This notion of integrating the GIS software to utilize an existing DBMS through standards is referred to as corporate or enterprise GIS. With the migration of GIS technology from being a research tool to being a decision support tool there is a requirement for it to be totally integrated with existing corporate activities, including accounting, reporting, and business functions.

There is a definite trend in the GIS marketplace towards a generic interface with external relational DBMS's. The use of an external DBMS, linked via a SQL interface, is becoming the norm. A flexibility as such is a strong selling point for any GIS. SQL is quickly becoming a standard in the GIS software marketplace.

Data Analysis

This part reviews data manipulation and analysis capabilities within a GIS. The focus is on reviewing spatial data analytical functions. This chapter categorizes analytical functions within a GIS and will be of most interest to technical staff and GIS operators.

- Manipulation and Transformation of Spatial Data
- Integration and Modeling of Spatial Data
- Integrated Analytical Functions

The major difference between GIS software and CAD mapping software is the provision of capabilities for transforming the original spatial data in order to be able to answer particular queries. Some transformation capabilities are common to both GIS and CAD systems, however, GIS software provides a larger range of analysis capabilities that will be able to operate on the topology or spatial aspects of the geographic data, on the non-spatial attributes of these data, or on both.

The main criteria used to define a GIS is its capability to transform and integrate spatial data.

Manipulation And Transformation Of Spatial Data

The maintenance and transformation of spatial data concerns the ability to input, manipulate, and transform data once it has been created. While many different interpretations exist with respect to what constitutes these capabilities some specific functions can be identified. These are reviewed below.

Coordinate Thinning

Coordinate thinning involves the weeding or reduction of coordinate pairs, e.g. X and Y, from arcs. This function is often required when data has been captured with too many vertices for the linear features. This can result in redundant data and large data volumes. The weeding of coordinates is required to reduce this redundancy.

The thinning of coordinates is also required in the map generalization process of linear simplification. Linear simplification is one component of generalization that is required when data from one scale, e.g. 1:20,000, is to be used and integrated with data from another scale, e.g. 1:100,000. Coordinate thinning is often done on features such as contours, hydrography, and forest stand boundaries.

Geometric Transformations

This function is concerned with the registering of a data layer to a common coordinate scheme. This usually involves registering selected data layers to a standard data layer already registered. The term rubber sheeting is often used to describe this function. Rubber sheeting involves stretching one data layer to meet another based on predefined control points of known locations. Two other functions may be categorized under geometric transformations. These involve warping a data layer stored in one data model, either raster or vector, to another data layer stored in the opposite data model. For example, often classified satellite imagery may require warping to fit an existing forest inventory layer, or a poor quality vector layer may require warping to match a more accurate raster layer.

Map Projection Transformations

This functionality concerns the transformation of data in geographic coordinates for an existing map projection to another map projection. Most GIS software requires that data layers must be in the same map projection for analysis. Accordingly, if data is acquired in a different projection than the other data layers it must be transformed. Typically 20 or more different map projections are supported in a GIS software offering.

Conflation - Sliver Removal

Conflation is formally defined as the procedure of reconciling the positions of corresponding features in different data layers. More commonly this is referred to as sliver removal. Often two layers that contain the same feature, e.g. soils and forest stands both with a specific lake, do not have exactly the same boundaries for that feature, e.g. the lake. This may be caused by a lack of coordination or data prioritization during digitizing or by a number of different manipulation and analysis techniques. When the two layers are combined, e.g. normally in polygon overlay, they will not match precisely and small sliver polygons will be created. Conflation is concerned with the process for removing these slivers and reconciling the common boundary.

There are several approaches for sliver removal. Perhaps the most common is allowing the user to define a priority for data layers in combination with a tolerance value.

Considering the soils and forest stand example the user could define a layer that takes precedence, e.g. forest stands, and a size tolerance for slivers. After polygon overlay if a polygon is below the size tolerance it is classified a sliver. To reconcile the situation the arcs of the data layer that has higher priority will be retained and the arcs of the other data layer will be deleted. Another approach is to simply divide the sliver down the centre and collapse the arcs making up the boundary. The important point is that all GIS software must have the capability to resolve slivers. Remember that it is generally much less expensive to reconcile maps manually in the map preparation and digitizing stage than afterwards.

Edge Matching

Edge matching is simply the procedure to adjust the position of features that extend across typical map sheet boundaries. Theoretically data from adjacent map sheets should meet precisely at map edges. However, in practice this rarely occurs. Misalignment of features can be caused by several factors including digitizing error, paper shrinkage of source maps, and errors in the original mapping. Edge matching always requires some interactive editing. Accordingly, GIS software differs considerably in the degree of automation provided.

Interactive Graphic Editing

Interactive graphic editing functions involve the addition, deletion, moving, and changing of the geographic position of features. Editing should be possible at any time. Most graphic editing occurs during the data compilation phase of any project. Remember typically 60 to 70 % of the time required to complete any project involves data compilation. Accordingly, the level of sophistication and ease of use of this capability is vitally important and should be rated highly by those evaluating GIS software. Many of the editing that is undertaken involves the cleaning up of topological errors identified earlier. The capability to snap to existing elements, e.g. nodes and arcs, is critical.

The functionality of graphic editing does not differ greatly across GIS software offerings. However, the user interface and ease of use of the editing functions usually does. Editing within a GIS software package should be as easy as using a CAD system. A cumbersome or incomplete graphic editing capability will lead to much frustration by the users of the software.

Integration and Modelling Of Spatial Data

The integration of data provides the ability to ask complex spatial questions that could not be answered otherwise. Often, these are inventory or locational questions such as how much ? or where ?. Answers to locational and quantitative questions require the combination of several different data layers to be able to provide a more complete and realistic answer. The ability to combine and integrate data is the backbone of GIS.

Often, applications do require a more sophisticated approach to answer complex spatial queries and what if ? scenarios. The technique used to solve these questions is called spatial modelling. Spatial modelling infers the use of spatial characteristics and methods in manipulating data. Methods exist to create an almost unlimited range of capabilities for data analysis by stringing together sets of primitive analysis functions. While some explicit analytical models do exist, especially in natural resource applications, most modelling formulae (models) are determined based on the needs of a particular project. The capability to undertake complex modelling of spatial data, on an ad hoc basis, has

helped to further the resource specialists understanding of the natural environment, and the relationship between selected characteristics of that environment.

The use of GIS spatial modelling tools in several traditional resource activities has helped to quantify processes and define models for deriving analysis products. This is particularly true in the area of resource planning and inventory compilation. Most GIS users are able to better organize their applications because of their interaction with, and use of, GIS technology. The utilization of spatial modelling techniques requires a comprehensive understanding of the data sets involved, and the analysis requirements.

The critical function for any GIS is the integration of data.

The raster data model has become the primary spatial data source for analytical modeling with GIS. The raster data model is well suited to the quantitative analysis of numerous data layers. To facilitate these raster modeling techniques most GIS software employs a separate module specifically for cell processing.

Integrated Analytical Functions in A GIS

Most GIS's provide the capability to build complex models by combining primitive analytical functions. Systems vary as to the complexity provided for spatial modelling, and the specific functions that are available. However, most systems provide a standard set of primitive analytical functions that are accessible to the user in some logical manner. Aronoff identifies four categories of GIS analysis functions. These are:

- Retrieval, Reclassification, and Generalization;
- Topological Overlay Techniques;
- Neighbourhood Operations; and
- Connectivity Functions.

The range of analysis techniques in these categories is very large. Accordingly, this section of the book focuses on providing an overview of the fundamental primitive functions that are most often utilized in spatial analyses.

Retrieval, Reclassification and Generalization

Perhaps the initial GIS analysis that any user undertakes is the retrieval and/or reclassification of data. Retrieval operations occur on both spatial and attribute data. Often data is selected by an attribute subset and viewed graphically. Retrieval involves the selective search, manipulation, and output of data without the requirement to modify the geographic location of the features involved.

Reclassification involves the selection and presentation of a selected layer of data based on the classes or values of a specific attribute, e.g. cover group. It involves looking at an attribute, or a series of attributes, for a single data layer and classifying the data layer based on the range of values of the attribute. Accordingly, features adjacent to one another that have a common value, e.g. cover group, but differ in other characteristics, e.g. tree height, species, will be treated and appear as one class. In raster based GIS software, numerical values are often used to indicate classes. Reclassification is an attribute generalization technique. Typically this function makes use of polygon patterning techniques such as crosshatching and/or color shading for graphic representation.

In a vector based GIS, boundaries between polygons of common reclassed values should be dissolved to create a cleaner map of homogeneous continuity. Raster reclassification intrinsically involves boundary dissolving. The dissolving of map boundaries based on a specific attribute value often results in a new data layer being created. This is often done for visual clarity in the creation of derived maps. Almost all GIS software provides the capability to easily dissolve boundaries based on the results of a reclassification. Some systems allow the user to create a new data layer for the reclassification while others simply dissolve the boundaries during data output.

One can see how the querying capability of the DBMS is a necessity in the reclassification process. The ability and process for displaying the results of reclassification, a map or report, will vary depending on the GIS. In some systems the querying process is independent from data display functions, while in others they are integrated and querying is done in a graphics mode. The exact process for undertaking a reclassification varies greatly from GIS to GIS. Some will store results of the query in query sets independent from the DBMS, while others store the results in a newly created attribute column in the DBMS. The approach varies drastically depending on the architecture of the GIS software.

Topological Overlay

The capability to overlay multiple data layers in a vertical fashion is the most required and common technique in geographic data processing. In fact, the use of a topological data structure can be traced back to the need for overlaying vector data layers. With the advent of the concepts of mathematical topology polygon overlay has become the most popular geoprocessing tool, and the basis of any functional GIS software package.

Topological overlay is predominantly concerned with overlaying polygon data with polygon data, e.g. soils and forest cover. However, there are requirements for overlaying point, linear, and polygon data in selected combinations, e.g. point in polygon, line in polygon, and polygon on polygon are the most common. Vector and raster based software differ considerably in their approach to topological overlay.

Raster based software is oriented towards arithmetic overlay operations, e.g. the addition, subtraction, division, multiplication of data layers. The nature of the one attribute map approach, typical of the raster data model, usually provides a more flexible and efficient overlay capability. The raster data model affords a strong numerically modelling (quantitative analysis) modelling capability. Most sophisticated spatial modelling is undertaken within the raster domain.

In vector based systems topological overlay is achieved by the creation of a new topological network from two or more existing networks. This requires the rebuilding of topological tables, e.g. arc, node, polygon, and therefore can be time consuming and CPU intensive. The result of a topological overlay in the vector domain is a new topological network that will contain attributes of the original input data layers. In this way selected queries can then be undertaken of the original layer, e.g. soils and forest cover, to determine where specific situations occur, e.g. deciduous forest cover where drainage is poor.

Most GIS software makes use of a consistent logic for the overlay of multiple data layers. The rules of Boolean logic are used to operate on the attributes and spatial properties of geographic features. Boolean algebra uses the operators AND, OR, XOR, NOT to see whether a particular condition is true or false. Boolean logic represents all possible

combinations of spatial interaction between different features. The implementation of Boolean operators is often transparent to the user.

To date the primary analysis technique used in GIS applications, vector and raster, is the topological overlay of selected data layers.

Generally, GIS software implements the overlay of different vector data layers by combining the spatial and attribute data files of the layers to create a new data layer. Again, different GIS software utilize varying approaches for the display and reporting of overlay results. Some systems require that topological overlay occur on only two data layers at a time, creating a third layer.

This pairwise approach requires the nesting of multiple overlays to generate a final overlay product, if more than two data layers are involved. This can result in numerous intermediate or temporary data layers. Some systems create a complete topological structure at the data verification stage, and the user merely submits a query string for the combined topological data. Other systems allow the user to overlay multiple data layers at one time. Each approach has its drawbacks depending on the application and the nature of the implementation. Determining the most appropriate method is based on the type of application, practical considerations such as data volumes and CPU power, and other considerations such personnel and time requirements. Overall, the flexibility provided to the operator and the level of performance varies widely among GIS software offerings.

Neighbourhood Operations

Neighbourhood operations evaluate the characteristics of an area surrounding a specific location. Virtually all GIS software provides some form of neighbourhood analysis. A range of different neighbourhood functions exist. The analysis of topographic features, e.g. the relief of the landscape, is normally categorized as being a neighbourhood operation. This involves a variety of point interpolation techniques including slope and aspect calculations, contour generation, and Thiessen polygons. Interpolation is defined as the method of predicting unknown values using known values of neighbouring locations. Interpolation is utilized most often with point based elevation data.

Elevation data usually takes the form of irregular or regular spaced points. Irregularly space points are stored in a Triangular Irregular Network (TIN). A TIN is a vector topological network of triangular facets generated by joining the irregular points with straight line segments. The TIN structure is utilized when irregular data is available, predominantly in vector based systems. TIN is a vector data model for 3-D data.

An alternative in storing elevation data is the regular point Digital Elevation Model (DEM). The term DEM usually refers to a grid of regularly space elevation points. These points are usually stored with a raster data model. Most GIS software offerings provide three dimensional analysis capabilities in a separate module of the software. Again, they vary considerably with respect to their functionality and the level of integration between the 3-D module and the other more typical analysis functions.

Without doubt the most common neighbourhood function is buffering. Buffering involves the ability to create distance buffers around selected features, be it points, lines, or areas. Buffers are created as polygons because they represent an area around a feature. Buffering is also referred to as *corridor or zone generation* with the raster data model. Usually, the results of a buffering process are utilized in a topological overlay with another data layer. For example, to determine the volume of timber within a selected

distance of a cutline, the user would first buffer the cutline data layer. They would then overlay the resultant buffer data layer, a buffer polygon, with the forest cover data layer in a clipping fashion. This would result in a new data layer that only contained the forest cover within the buffer zone. Since all attributes are maintained in the topological overlay and buffering processes, a map or report could then be generated.

Buffering is typically used with point or linear features. The generation of buffers for selected features is frequently based on a distance from that feature, or on a specific attribute of that feature. For example, some features may have a greater zone of influence due to specific characteristics, e.g. a primary highway would generally have a greater influence than a gravel road. Accordingly, different size buffers can be generated for features within a data layer based on selected attribute values or feature types.

Connectivity Analysis: The distinguishing feature of connectivity operations is that they use functions that accumulate values over an area being traversed. Most often these include the analysis of surfaces and networks. Connectivity functions include proximity analysis, network analysis, spread functions, and three dimensional surface analysis such as visibility and perspective viewing. This category of analysis techniques is the least developed in commercial GIS software. Consequently, there is often a great difference in the functionality offered between GIS software offerings. Raster based systems often provide the more sophisticated surface analysis capabilities while vector based systems tend to focus on linear network analysis capabilities. However, this appears to be changing as GIS software becomes more sophisticated, and multi-disciplinary applications require a more comprehensive and integrated functionality. Some GIS offerings provide both vector and raster analysis capabilities. Only in these systems will one fund a full range of connectivity analysis techniques.

Proximity analysis: techniques are primarily concerned with the proximity of one feature to another. Usually proximity is defined as the ability to identify any feature that is near any other feature based on location, attribute value, or a specific distance. A simple example is identifying all the forest stands that are within 100 metres of a gravel road, but not necessarily adjacent to it. It is important to note that neighbourhood buffering is often categorized as being a proximity analysis capability. Depending on the particular GIS software package, the data model employed, and the operational architecture of the software it may be difficult to distinguish proximity analysis and buffering.

The identification of adjacency is another proximity analysis function. Adjacency is defined as the ability to identify any feature having certain attributes that exhibit adjacency with other selected features having certain attributes. A typical example is the ability to identify all forest stands of a specific type, e.g. specie, adjacent to a gravel road.

Network analysis is a widely used analysis technique. Network analysis techniques can be characterized by their use of feature networks. Feature networks are almost entirely comprised of linear features. Hydrographic hierarchies and transportation networks are prime examples. Two example network analysis techniques are the allocation of values to selected features within the network to determine capacity zones, and the determination of shortest path between connected points or nodes within the network based on attribute values. This is often referred to as route optimization. Attribute values may be as simple as minimal distance, or more complex involving a model using several attributes defining rate of flow, impedance, and cost.

Three dimensional analysis involves a range of different capabilities. The most utilized is the generation of perspective surfaces. Perspective surfaces are usually represented by a

wire frame diagram reflecting profiles of the landscape, e.g. every 100 metres. These profiles viewed together, with the removal of hidden lines, provide a three dimensional view. As previously identified, most GIS software packages offer 3-D capabilities in a separate module. Several other functions are normally available.

These include the following functions :

- User definable vertical exaggeration, viewing azimuth, and elevation angle;
- Identification of view sheds, e.g. seen versus unseen areas;
- The draping of features, e.g. point, lines, and shaded polygons onto the perspective surface;
- Generation of shaded relief models simulating illumination;
- generation of cross section profiles;
- presentation of symbology on the 3-D surface; and
- line of sight perspective views from user defined viewpoints.

While the primitive analytical functions have been presented the reader should be aware that a wide range of more specific and detailed capabilities do exist.

MODULE-II

GIS TECHNOLOGIES AND APPLICATIONS

MODULE-II: GIS TECHNOLOGIES AND APPLICATIONS

Geospatial Technologies: Geospatial technologies is a term used to describe the range of modern tools contributing to the geographic mapping and analysis of the Earth and human societies. These technologies have been evolving in some form since the first maps were drawn in prehistoric times. In the 19th century, the long important schools of cartography and mapmaking were joined by aerial photography as early cameras were sent aloft on balloons and pigeons, and then on airplanes during the 20th century. The science and art of photographic interpretation and map making was accelerated during the Second World War and during the Cold War it took on new dimensions with the advent of satellites and computers. Satellites allowed images of the Earth′s surface and human activities therein with certain limitations. Computers allowed storage and transfer of imagery together with the development of associated digital software, maps, and data sets on socioeconomic and environmental phenomena, collectively called geographic information systems (GIS). An important aspect of a GIS is its ability to assemble the range of geospatial data into a layered set of maps which allow complex themes to be analyzed and then communicated to wider audiences. This ′layering is enabled by the fact that all such data includes information on its precise location on the surface of the Earth, hence the term ′geospatial′.

Especially in the last decade, these technologies have evolved into a network of national security, scientific, and commercially operated satellites complemented by powerful desktop GIS. In addition, aerial remote sensing platforms, including unmanned aerial vehicles (e.g. the GlobalHawk reconnaissance drone), are seeing increased non-military use as well. High quality hardware and data is now available to new audiences such as universities, corporations, and non-governmental organizations. The fields and sectors deploying these technologies are currently growing at a rapid pace, informing decision makers on topics such as industrial engineering, biodiversity conservation, forest fire suppression, agricultural monitoring, humanitarian relief, and much more.

There are now a variety of types of geospatial technologies including the following:

Remote Sensing: imagery and data collected from space- or airborne camera and sensor platforms. Some commercial satellite image providers now offer images showing details of one-meter or smaller, making these images appropriate for monitoring humanitarian needs and human rights abuses.

Geographic Information Systems (GIS): a suite of software tools for mapping and analyzing data which is georeferenced (assigned a specific location on the surface of the Earth, otherwise known as geospatial data). GIS can be used to detect geographic patterns in other data, such as disease clusters resulting from toxins, sub-optimal water access, etc.

Global Positioning System (GPS): a network of U.S. Department of Defense satellites which can give precise coordinate locations to civilian and military users with proper receiving equipment (note: a similar European system called Galileo will be operational within the next several years while a Russian system is functioning but restricted).

Internet Mapping Technologies: software programs like Google Earth and web features like Microsoft Virtual Earth are changing the way geospatial data is viewed and shared. The developments in user interface are also making such technologies available to a wider audience whereas traditional GIS has been reserved for specialists and those who invest time in learning complex software programs.

Remote Sensing: All methods of collecting information about Earth without touching it are forms of remote sensing. For example, photographing a flooded river from an airplane is a form of remote sensing, but sampling its water is not. Scientists mount remote-sensing devices such as cameras and radars on ships, airplanes, or satellites that can cruise above the land, sea, or ocean floor, collecting data from large areas quickly. Most remote-sensing technologies use electromagnetic waves (light or radio waves) because they are fast, interact in revealing ways with solid matter, and can pass easily through both air and vacuum.

Active or Passive: A given remote-sensing technology may be either active or passive. Passive remote-sensing technologies collect whatever waves happen to be coming their way and form them into an image. They usually are tuned to a particular band of the electromagnetic spectrum, such as visible light or infrared light (heat radiation). Active remote-sensing systems, on the other hand, beam radio pulses, sound waves, or laser beams at their targets and construct an image from the echoes.

Remote sensing is important for water science because water is widely distributed. Precipitation falls unevenly and intermittently over large areas; rivers drain irregularly-shaped watersheds; lakes are dotted randomly over vast territories. On-site measurements provide accurate information at single points, but aircraft or satellites observe entire landscapes at once. Furthermore, remote-sensing observations are easy to repeat; a satellite, for example, may pass over the same part of the Earth repeatedly. It is straightforward to image the same part of Earth repeatedly from space, making it possible to monitor both local and large-scale changes.

Remote-sensing imagery acquired by passive and active systems has been used for almost every conceivable type of water-science research, including the study of waves, currents, and oceanic circulation patterns; the detection of marine organisms; the inventorying of lakes; and the mapping of wetlands , ocean floors, land-water boundaries, floodplains , ice movement, snow cover, oil spills, shoreline changes, and many other features. Remote-sensed data are key in flood prediction and prevention, irrigation and drainage studies, water quality management, groundwater protection, and other water resource investigations.

***Satellites*:** The Landsats (for land -sensing sat ellites) have for decades been the most important remote-sensing satellites, though many others also have been launched. The first Landsat was lofted by the United States in 1972 and the seventh was functioning as of 2002. Landsats circle Earth at a low altitude of 420 to 912 kilometers (260 to 570 miles), passing over the North and South Poles rather than circling the equator. This path means that Earth rotates inside the circular orbit of each satellite, constantly presenting new territory to the satellite's view. The data collected by the Landsats are made publicly available by the U.S. government.

Satellite images often record visible light or other forms of radiation. Visible-light images are useful for determining the locations and sizes of rivers, lakes, ice-covered or snow-covered areas, and other surface features. Images made from infrared light (which can be felt on the skin as radiant heat but not seen) provide different information. For example, infrared images can reveal heat plumes in bodies of water such as those occurring when a nuclear power plant disposes of hot water from its cooling system into a river. Creating detailed maps of such heat plumes by taking on-the-spot temperature readings would require thousands of measurements over a large area of moving water, an effectively impossible task. Infrared images also are used to classify vegetation cover by type, to

monitor droughts, to visualize changes in ocean currents, and for other water-related purposes.

***Radar*:** Radar works by sending radio pulses toward objects and recording how long the echoes take to return, and is the most common active remote-sensing technology. Radar is a superb tool for measuring relief (i.e., the height variations of land or water surfaces). Precise knowledge of topography (land relief) is essential to understanding the collection of rainwater and snowmelt by rivers, which is in turn useful for flood prediction, agriculture, and other purposes. Radar observations of water waves give information on winds and currents; satellite-based radar also has mapped subtle variations in sea level due to irregularities in Earth's gravitational field.

Radio waves pass readily through clouds and ice. Radar's ability to see through ice makes it an ideal tool for measuring the thickness of ice and snowfields. The Greenland and Antarctic ice caps, which contain nearly 87 percent of the world's fresh water, have been sounded with radar, leading to the discovery of over 70 Antarctic lakes. One, called Lake Vostok, is the size of Lake Ontario and is buried beneath kilometers of ice.

Radar studies of water and ice are not limited to Earth. The U.S. National Aeronautics and Space Administration (NASA) has proposed that spacecraft-mounted radar be used to peer through the icy crust that covers Europa, one of the moons of Jupiter, to see whether a global ocean lies hidden beneath it. The European Space Agency's Mars Express mission, scheduled for launch in 2003, was expected to carry radar to map ice deposits in the soils of Mars.

***Sonar*:** Sonar, another active remote-sensing technology, is similar to radar but uses sound waves rather than radio waves. Most of the world's water, the 97 percent that is contained in the oceans, can be explored only superficially using light or radar because water absorbs electromagnetic waves. This makes sonar the only remote-sensing technology that can explore the bulk of the world's seas and other deep waters. Sonar systems mounted on ships' hulls or in special torpedoes towed behind ships ("sonar fish") have been used since World War II to map the ocean-floor topography of the world, and the knowledge thus gained has revolutionized the knowledge of geology.

For more detailed study, Refer Paper-2: Remote Sensing Technology and Law

Global Positioning System (GPS): GPS is a system of twenty-four satellites that allows the coordinates of any point on or near Earth's surface to be measured with extremely high precision. The satellites of the GPS are arranged evenly around the Earth so that at least four are visible at all times from any point on Earth's surface. As one satellite sets below the horizon, another always rises somewhere else.

A special GPS receiver unit, usually handheld, is used to receive signals broadcast by the GPS satellites and to compute its own location from those signals. The GPS is a high-tech shortcut to the goal that surveyors and navigators have long sought by slower, less accurate means: namely, precise knowledge of one's own location. The GPS has only been in widespread use since more affordable GPS receivers first became available in the early 1990s.

The coordinates supplied by a GPS receiver must be matched to other data to be meaningful. A GPS receiver relays where something is located, but a human operator must specify what that something is: a rainfall measurement, well, or some other datum or

object. The GPS is not a remote-sensing system because it does not collect data about the Earth. Rather, it facilitates the collection of data at specific points on Earth's surface.

For example, after Hurricane Dennis eroded beaches along the North Carolina shore in 1999, crews from the U.S. Geological Survey drove trucks along 80 kilometers (50 miles) of beach, mapping the new shoreline with GPS receivers. Aerial photography and airborne scanning lasers also were deployed to examine the altered coastline. These remote-sensing missions imaged more coastline than GPS, but with lower precision. Additionally, in 1998, researchers used GPS to accurately locate wells near the South Platte River in Colorado. This dataset was combined with satellite images of crop patterns and surface-water resources to determine how much water could be drawn from the wells and from the surface resources without depleting either.

Geographic Information Systems (GIS): GIS is a computer system that can be used for scientific research and for water planning and management. This technology integrates powerful computer capabilities with the unique visual perspective of a good old-fashioned map.

It allows users to assemble, store, manipulate, and display geographically referenced information—data that can be identified according to its locations.

GIS requires the use of computer hardware, software, data, and specialists to study data related to Earth and the interconnections between its various features. GIS links information about where things are with information about what things are like. It is much more sophisticated than a paper map, as it can combine many layers of information about a particular spatial area to help yield a better understanding of that place. The layers of information to be studied depend on the researcher's purposes.

The information organized in a GIS comes from many sources, including remote sensing, the GPS, censuses, rock and soil samples, stream gage systems, weather stations, and wildlife sightings. GIS stores information about a geographic area as a collection of themed layers or maps. An individual layer can be anything that contains similar features (e.g., lakes, streets, postal codes, agricultural lands). Reliable and accurate data are necessary for creating high-quality GIS maps.

GIS is utilized in many industries, including business, transportation, communications, and defense; similarly, GIS is an important tool for analyzing water policy and science issues. Because all the layered maps in a given GIS cover the same geographic area, it is possible to link and compare different kinds of data. For example, information about a river network or watershed can be compiled using GIS. A watershed represents the landscape view of water resources, and the effects of spatial patterns of soils, land use, land cover, and urban development can be studied.

Combining topography with vegetation and soil type, for example, may help hydrologists understand how water drains from a given landscape, and thus enable them to predict flooding or pollution transport. GIS makes it possible for earth scientists, city planners, farmers, the military, water resource managers, and many other users to handle the vast quantity of information available from remote sensing, GPS, geology, biology, and other sources.

GIS and other geospatial technologies provide significant input for the management and analysis of large volumes of data, allowing for better understanding of environmental

processes and for better management of human activities to ensure environmental quality and economic vitality.

Technology used in GIS

Data creation: Modern GIS technologies use digital information, for which various digitized data creation methods are used. The most common method of data creation is digitization, where a hard copy map or survey plan is transferred into a digital medium through the use of a computer-aided design program with geo-referencing capabilities. With the wide availability of rectified imagery (both from satellite and aerial sources), heads-up digitizing is becoming the main avenue through which geographic data is extracted. Heads-up digitizing involves the tracing of geographic data directly on top of the aerial imagery instead of through the traditional method of tracing the geographic form on a separate digitizing tablet.

Relating information from different sources: If you could relate information about the rainfall of a state to aerial photographs of county, you might be able to tell which wetlands dry up at certain times of the year. A GIS, which can use information from many different sources in many different forms, can help with such analyses. The primary requirement for the source data consists of knowing the locations for the variables. Location may be annotated by x, y, and z coordinates of longitude, latitude, and elevation, or by other geocode systems like postal codes. Any variable that can be located spatially can be fed into a GIS. Different kinds of data in map form can be entered into a GIS.

A GIS can also convert existing digital information, which may not yet be in map form, into forms it can recognize and use. For example, digital satellite images generated through remote sensing can be analyzed to produce a map-like layer of digital information about vegetative covers. Likewise, census or hydrologic tabular data can be converted to map-like form, serving as layers of thematic information in a GIS.

Data representation: GIS data represents real world objects such as roads, land use, elevation with digital data. Real world objects can be divided into two abstractions: discrete objects (a house) and continuous fields (rain fall amount or elevation). There are two broad methods used to store data in a GIS for both abstractions: Raster and Vector.

Raster: A raster data type is, in essence, any type of digital image. Anyone who is familiar with digital photography will recognize the pixel as the smallest individual unit of an image. A combination of these pixels will create an image, distinct from the commonly used scalable vector graphics, which are the basis of the vector model. While a digital image is concerned with the output as representation of reality, in a photograph or art transferred to computer, the raster data type will reflect an abstraction of reality. Aerial photos are one commonly used form of raster data, with only one purpose, to display a detailed image on a map or for the purposes of digitization. Other raster data sets will contain information regarding elevation, a DEM (digital Elevation Model), or reflectance of a particular wavelength of light.

Digital elevation model, map, and vector data, Raster data type consists of rows and columns of cells each storing a single value. Raster data can be images (raster images) with each pixel containing a color value. Additional values recorded for each cell may be a discrete value, such as land use, a continuous value, such as temperature, or a null value if no data is available. While a raster cell stores a single value, it can be extended by using raster bands to represent RGB (red, green, blue) colors, colormaps (a mapping between a

thematic code and RGB value), or an extended attribute table with one row for each unique cell value. The resolution of the raster data set is its cell width in ground units.

Raster data is stored in various formats; from a standard file-based structure of TIF, JPEG formats to binary large object (BLOB) data stored directly in a relational database management system (RDBMS) similar to other vector-based feature classes. Database storage, when properly indexed, typically allows for quicker retrieval of the raster data but can require storage of millions of significantly sized records.

Vector: A simple vector map, using each of the vector elements: points for wells, lines for rivers, and a polygon for the lake. In a GIS, geographical features are often expressed as vectors, by considering those features as geometrical shapes. In the popular ESRI Arc series of programs, these are explicitly called shape files. Different geographical features are best expressed by different types of geometry:

Points: Zero-dimensional points are used for geographical features that can best be expressed by a single grid reference; in other words, simple location. For example, the locations of wells, peak elevations, features of interest or trailheads. Points convey the least amount of information of these file types.

Lines or polylines: One-dimensional lines or polylines are used for linear features such as rivers, roads, railroads, trails, and topographic lines.

Polygons: Two-dimensional polygons are used for geographical features that cover a particular area of the earth's surface. Such features may include lakes, park boundaries, buildings, city boundaries, or land uses. Polygons convey the most amount of information of the file types.

Each of these geometries are linked to a row in a database that describes their attributes. For example, a database that describes lakes may contain a lake's depth, water quality, pollution level. This information can be used to make a map to describe a particular attribute of the dataset. For example, lakes could be coloured depending on level of pollution. Different geometries can also be compared. For example, the GIS could be used to identify all wells (point geometry) that are within 1-mile (1.6 km) of a lake (polygon geometry) that has a high level of pollution.

Vector features can be made to respect spatial integrity through the application of topology rules such as 'polygons must not overlap'. Vector data can also be used to represent continuously varying phenomena. Contour lines and triangulated irregular networks (TIN) are used to represent elevation or other continuously changing values. TINs record values at point locations, which are connected by lines to form an irregular mesh of triangles. The face of the triangles represent the terrain surface.

Data Sources for Geographic Information Systems: Data sources for GISs include the following:

- existing maps;
- aerial photographs;
- satellite images

Types of Geographic Information System Platforms

There are several types of GIS platforms available, such as:

- desktop GIS;
- server GIS;
- Web GIS;
- Mobile GIS.

Desktop Geographic Information Systems

Desktop GIS applications are software and technology that run on a single computer(personal), which allows users to input, store, digitize, analyze, and manipulate geospatial data. Basically desktop GIS is meant for a single user, it cannot be connected to other computers. The existing data are always safe and private with desktop GIS as they are completely isolated from other computers. The user always needs his or her GIS-installed computer to work on GIS. Desktop GISs are divided into two groups:

- Licensed desktop GIS;
- Open source desktop GIS.

Licensed desktop GIS is paid software whereby the user is provided with a single computer license and is equipped with predefined tools. ArcGIS is a paid software.

Open source desktop GIS is free software that anyone can install and work on a computer.QGIS is a free software that fulfills all the basic necessities of the end user.

Server Geographic Information System:

This a software system that offers all GIS facilities and functionalities over a number ofconnected systems within an organization or off site in a cloud computing environment.Many single computers are connected to one another and each and every computer is provided with GIS to share all GIS services.

Web Geographic Information System

A Web GIS is a distributed information system consisting at least a server and a client.The server is equipped with the GIS and the client uses a Web browser or any desktop software that can work online (via the Internet). It is a communication between client and server using Web technology.

The main advantage of Web GIS is the ability of the client and server to work all across the globe. The client can work from anywhere in the world via a Web browser with the assigned log-in credentials and needs to carry a GIS-installed computer. A team can work simultaneously on the same application while staying at different locations. Real-time monitoring is possible with Web GIS. The main application of Web GIS is ambulance services.

Mobile Geographic Information System

Mobile GIS allows users to access mapping services on mobile devices such as mobile phones and tablets. It works on the concept of wireless GIS mapping. The two main applications areas are:

- field-based GIS services;
- location-based services.

The following technologies are assimilated in mobile GIS:

- Mobile devices;
- Global positioning system (GPS);
- Internet-based GIS access to wireless communications.

GIS/Geospatial Data Formats:

Overview

Geospatial data is created, shared, and stored in many different formats. The two primary data types are raster and vector. Vector data is represented as either points, lines, or polygons. Discrete (or thematic) data is best represented as vector. Data that has an exact location, or hard boundaries are typically shown as vector data. Examples are county boundaries, the location of roads and railroads using lines, or point data indicating the location of fire hydrants.

By contrast, raster data is best suited for continuous data, or information that does not have hard boundaries or locations. As rasters, the data are viewed as a series of grid cells where each cell has a value representing the feature being observed. Think of raster data as appropriate for modeling surfaces like elevation, temperature, precipitation, or soil Ph. These phenomena are measured at intervals (think weather stations), and values in between are interpolated to create a continuous surface. Raster data also includes remote sensing imagery, like aerial photography and satellite imagery.

Vector Formats:

SHP: Shapefile

The ESRI Shapefile has become an industry standard geospatial data format, and is compatible to some extent with practically all recently released GIS software. To have a complete shapefile, you must have at least 3 files with the same prefix name and with the following extensions: .shp = shapefile, .shx = header and .dbf = associated database file. Additionally, you may have a .prj = Projection file, a .lyr = layer file, and other index files. All these files must be saved in the same workspace.

SDC: Smart Data Compression

SDC is ESRI's highly compressed format, which is directly readable by ArcGIS software.

GDB: Geodatabase

The file geodatabase is a collection of geographic datasets of various types, with the most basic types being vector, raster, and tabular data. There are three types of geodatabases: file, personal, and ArcSDE. Geodatabases are the native data format for ESRI's ArcGIS.

ArcInfo Coverage

An ArcInfo coverage has been phased out and is rarely seen/used today. It has largely been replaced by the geodatabase format. Coverages do not have an individual file extension. Instead it is composed of two folders within a "workspace" which each contain multiple files. One of the two folders carries the name of the coverage, and contains a number of various .adf files. The other folder is an "info" folder, which typically contains .dat and .nit files for all the coverages and grids in the workspace.

E00: Arc Export or Interchange Format

.e00 files are also rarely seen/used today, but are essentially ArcInfo Interchange or export files, used to conveniently copy and move ArcInfo GIS coverages (see above) and grids (see below). An .e00 file must be "imported" and converted in order to use the data in ArcGIS or other GIS software.

Raster Formats:

ArcInfo Grid

An ArcInfo Grid does not have an individual file extension. Instead it is composed of two folders within a "workspace" which each contain multiple files. One of the two folders carries the name of the grid, and contains a number of various .adf files. The other folder is an "info" folder, which typically contains .dat and .nit files for all the coverages and grids in the workspace.

Band Interleaved by Line (BIL), Band Interleaved by Pixel (BIP), and Band Sequential (BSQ).

BIL, BIP, and BSQ are formats produced by remote-sensing systems. The primary difference among them is the technique used to store brightness values captured simultaneously in each of several colors or spectral bands.

DEM (Digital Elevation Model)

DEM is a raster format used by the USGS to record elevation information. Unlike other raster file formats, DEM cells do not represent color brightness values, but rather the elevations of points on the earth′s surface.

GeoTIFF

As part of the header of the TIFF file, this provides the Lat/Long boundary extent of the data.

LiDAR

Light Detection and Ranging (LiDAR), is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth. File formats vary by deliverable - but raw LiDAR point cloud data has a .LAS file extension. A DEM can be one deliverable from LiDAR.

GIS Software

Overview:

Geographic information system (GIS) solutions automatically produce informational maps after they're fed a set of data. It's easier to understand how trends influence different

geographical areas when numerical tables get visually transformed in this way. Almost any type of organization can find this kind of application helpful since it provides a new way to visualize otherwise esoteric data.

GIS programs provide an overall framework for gathering, managing, and interpreting information. This gives businesses the ability to develop an actionable plan from raw numbers they've collected. While this kind of software has been around for decades, developers are starting to make mapping apps that can autonomously analyze any input they're given. Some of the best GIS software packages can even identify trends based on prior experience.

History of GIS Software: While the earliest modern mapping program was developed in the early 1960s, GIS concepts go back to the earliest mechanical computers. Cartographers in the 19th century used programs encoded on punch cards to help them interpret mathematical data they would then share with a conventional drafting technician. Improvements in visual display technology helped to eliminate the need for paper drafting in the early mainframe era.

Computer-aided topography and demographic studies were already commonplace in many governmental and enterprise organizations by the late 1970s. The rise of graphical user interfaces coupled with public domain survey charts soon made it possible for smaller businesses and county agencies to use GIS packages as part of their own studies.

Due to the fact that much of the early research in the field was done by public sector technicians, open-source GIS solutions appeared on the market fairly quickly. Considering that detailed street-level maps are easily accessible for free on the Internet, open-source development has continued to dominate the field in the modern age as well.

GIS Developments & Trends: Different GIS programs used various file formats to store maps for many years. While users might not be immediately aware of this fact since they seldom have to load their own maps, this did make it so businesses were locked into a certain cartographic library depending on which application they decided to invest in.

In order to share geospatial data across the Internet and especially between mobile devices, almost all apps used today adhere at least in part to a specific format and transfer protocol. This is giving users the freedom to download and use any set of maps they'd like.

Solutions that use predictive reasoning to automatically analyze data are also becoming more common. These programs apply the same kind of artificial intelligence (AI) technology used in video games. AI modules read numerical data and then compare it to other information available about a geographical area. This can help to uncover trends that might otherwise be difficult for a human technician to find.

Problems & Solutions: Information overload can be an issue for even the smallest firms these days. In part, this is due to the large amount of numerical data that companies have to process when it comes to clients. Collecting all of this data can also be expensive, and firms without a clear path to monetization might not feel it's worthwhile to continue maintaining their databases. Moreover, keeping tabs on large databases can become extremely expensive over time.

Using a GIS program can solve all of these problems. Mapping statistics onto a tangible map can help make sense of them by giving technicians an easy way to visualize what's going on. Some firms use this to find out which areas are more readily ordering different

products. They can then focus their marketing campaigns on areas they haven't currently attempted. A mapping system can also help them evaluate market access in the future, after they've made changes. Some of the best GIS software currently available can even develop a business plan based on these maps, which helps when it comes time for monetization.

Organizations don't just use GIS software for marketing and topography, however. Healthcare and insurance groups use it to track the spread of certain maladies. Logistics firms now use a similar application to track vehicles and identify problems in a production chain. Some manufacturing firms have started to use their own GIS system to identify and solve supply issues. Real estate firms and land developers were among the earliest adopters of this technology. They've long used it to figure out consumer home buying patterns, the best way to develop land, and the locations of areas with seriously underdeveloped lots. All of these use cases can save quite a bit of money for the operators.

Storage still tends to be a major problem in many firms, but IT departments are now able to deploy their chosen GIS program in a cloud environment. Using a cloud host can eliminate the need for complicated local storage infrastructure, and it might also help firms who have been looking to outsource some technology solutions.

List of GIS software

Commercial or proprietary GIS software

Most widely used notable proprietary software applications and providers:

- ESRI – Products include ArcView 3.x, ArcGIS, ArcSDE, ArcIMS, and ArcWeb services.
- GRAM++ GIS – Low-cost GIS software product developed by CSRE, IIT Bombay.
- Autodesk – Products include MapGuide and other products that interface with its flagship AutoCAD software package.
- Cadcorp – Developers of GIS software and OpenGIS standard
- Intergraph – Products include GeoMedia, GeoMedia Profesional, GeoMedia WebMap
- ERDAS IMAGINE – A proprietary GIS, Remote Sensing, and Photogrammetry software developed by Leica Geosystems Geospatial Imaging.
- SuperGeo – Products include SuperGIS Desktop & extensions, SuperPad Suite, SuperWebGIS & extensions, SuperGIS Engine & extensions, SuperGIS Network Server and GIS services.
- SuperMap GIS – Products include SuperMap iServer .NET/Java, SuperMap Deskpro, SuperMap Objects, SuperMap Express, SuperMap IS .NET, eSuperMap, SuperNavigation Engine, FieldMapper and services.
- IDRISI – Proprietary GIS product developed by Clark Labs.
- MapInfo – Products include MapInfo Professional and MapXtreme. integrates GIS software, data and services.
- MapPoint – Proprietary GIS product developed by Microsoft.
- Caliper – Products include Maptitude, TransCAD and TransModeler. Develops GIS and the only GIS for transportation.
- Pictometry – Proprietary software which allows oblique images to be draped with shapefiles.

- Black Coral Inc — a leading edge product company developing geospatial collaboration capabilities that enable better outcomes for personnel and tactical teams operating in emergency response and military environments.
- STAR-APIC – european GIS developer, offers GIS products (WinSTAR, STAR GIS), spatial data servers (STAR Server, STAR NeXt, GEOSPatial Hub), GIS-based business solutions (AquaSTAR, STAR ELEC, PipeGuardian, etc.).
- CARIS (Computer Aided Resource Information System) – GIS systems for hydrography and cadastral systems.
- GMS – Three-dimensional environment for building geologic and groundwater models
- Manifold System – Low-cost GIS software package.
- Oracle Spatial – Product allows users to perform basic geographic operations and store common spatial data types in a native Oracle environment.
- Orbit GIS Generic and multi-purpose GIS toolkit, written in Java.
- Safe Software – Spatial ETL products including FME, SpatialDirect and the ArcGIS Data Interoperability Extension.
- Smallworld – developed in Cambridge
- TatukGIS – Products include a GIS development toolkit, Internet Map Server, GIS Editor, free GIS Viewer, Aerial Imagery Corrector.
- Axpand – Proprietary GIS cartography product developed by Axes Systems. Modules include data import/export, automatic generalization, visualization and on-screen editing, pre-print configuration.

Open source software

Most widely used open source applications:

- GRASS – Originally developed by the U.S. Army Corps of Engineers, open source: a complete GIS
- MapServer – Web-based mapping server, developed by the University of Minnesota.
- Chameleon – Environments for building applications with MapServer.
- GeoNetwork opensource – A catalog application to manage spatially referenced resources
- GeoTools – Open source GIS toolkit written in Java, using Open Geospatial Consortium specifications.
- gvSIG – Open source GIS written in Java.
- ILWIS – ILWIS (Integrated Land and Water Information System) integrates image, vector and thematic data.
- JUMP GIS – Java Unified Mapping Platform.
- MapWindow GIS – Free, open source GIS desktop application and programming component.
- OpenLayers – open source AJAX library for accessing geographic data layers of all kinds, originally developed and sponsored by MetaCarta
- PostGIS – Spatial extensions for the open source PostgreSQL database, allowing geospatial queries.
- Quantum GIS – QGIS is a user friendly Open Source GIS that runs on Linux, Unix, Mac OSX, and Windows.
- TerraView – GIS desktop that handles vector and raster data stored in a relational or geo-relational database.

Other GIS software

- AccuGlobe – Fully functional GIS and geoanalysis software platform for Windows developed by DDTI (ddti.net) and available free of charge, but not open source.
- CrossView for ArcGIS – created by A-Prime Software, CrossView is a wizard-based ArcGIS plug-in, which enables map cross-sectioning and profile creation.
- GeoBase – Geospatial platform developed by Telogis. A particular focus is placed on real-time processing for reverse-geocoding, geofencing, etc.
- LandSerf – Free GIS written in Java
- My World GIS – Intuitive low-cost GIS platform for Windows and Mac OSX with robust/intuitive geoprocessing tools, developed for educational.
- Panorama – Russian GIS for military uses.
- SPRING – GIS software developed at INPE –
- SavGIS – Free and complete GIS software available in French, English and Spanish
- MapTools – Suite of open-source GIS products and platforms.
- OpenStreetMap – Online map viewer, with map editing capability.

Data creation: GIS processing software is used for the task of preparing data for use within a GIS. This transforms the raw or legacy geographic data into a format usable by GIS products. For example an aerial photograph may need to be stretched using photogrammetry so that its pixels align with longitude and latitude gradations. This can be distinguished from the transformations done within GIS analysis software by the fact that these changes are permanent, more complex and time consuming. Thus, a specialized high-end type of software is generally used by a skilled person in GIS processing aspects of computer science for digitization and analysis. Raw geographic data can be edited in many standard database and spreadsheet applications and in some cases a text editor may be used as long as care is taken to properly format data.

A geo-database is a database with extensions for storing, querying, and manipulating geographic information and spatial data.

Management and analysis: GIS analysis software takes GIS data and overlays or otherwise combines it so that the data can be visually analysed. It can output a detailed map, or image used to communicate an idea or concept with respect to a region of interest. This is usually used by persons who are trained in cartography, geography or a GIS professional as this type of application is complex and takes some time to master. The software performs transformation on raster and vector data sometimes of differing datums, grid system, or reference system, into one coherent image. It can also analyse changes over time within a region. This software is central to the professional analysis and presentation of GIS data. Examples include the ArcGIS family of ESRI GIS applications, Smallworld, Gram++ and GRASS.

Statistical: GIS statistical software uses standard database queries to retrieve data and analyse data for decision making. For example, it can be used to determine how many persons of an income of greater than 60,000 live in a block. The data is sometimes referenced with postal codes and street locations rather than with geodetic data. This is used by computer scientists and statisticians with computer science skills, with an objective of characterizing an area for marketing or governing decisions. Standard DBMS

can be used or specialized GIS statistical software. These are many times setup on servers so that they can be queried with web browsers. Examples are MySQL or ArcSDE.

Readers: GIS readers are computer applications that are designed to allow users to easily view digital maps as well as view and query GIS-managed data. By definition, they usually allow very little if any editing of the map or underlying map data. Readers can be normal standalone applications that need to be installed locally, though they are often designed to connect to data servers over the Internet to access the relevant information. Readers can also be included as an embedded application within a web page, obviating the need for local installation. Readers are designed to be relatively simple and easy to use as well as free.

Web API: This is the evolution of the scripts that were common with most early GIS systems. An Application Programming Interface (API) is a set of subroutines designed to perform a specific task. GIS APIs are designed to manage GIS data for its delivery to a web browser client from a GIS server. They are accessed with commonly used scripting language such as VBA or JavaScript. They are used to build a server system for the delivery of GIS that is to make available over an Intranet.

Distributed GIS: Distributed GIS concerns itself with Geographical Information Systems that do not have all of the system components in the same physical location. This could be the processing, the database, the rendering or the user interface. Examples of distributed systems are web-based GIS, Mobile GIS, Corporate GIS and GRID computing.

Mobile GIS: GIS has seen many implementations on mobile devices. With the widespread adoption of GPS, GIS has been used to capture and integrate data in the field.

Open-source GIS software: Many GIS tasks can be accomplished with open-source GIS software, which are freely available over Internet downloads. With the broad use of non-proprietary and open data formats such as the Shape File format for vector data and the Geotiff format for raster data, as well as the adoption of OGC standards for networked servers, development of open source software continues to evolve, especially for web and web service oriented applications. Well-known open source GIS software includes GRASS GIS, Quantum GIS, MapServer, uDig, OpenJUMP, gvSIG and many others. PostGIS provides an open source alternative to geo-databases such as Oracle Spatial, and ArcSDE.

Maps: Common problems cannot be solved without intervention and intervention is impossible without visualization offered by ′Maps′. A table of data may present facts & figures, but it doesn′t tell a story. A static table of data can help us realize there is a problem, but it cannot tell us accurately ′where′. Only maps can accurately point out which are the most affected areas, enabling us to know why those areas have got most affected, what can be done to reduce the impact etc. GIS-based mapping is the answer to all. Maps define The Power of Where.

As Jim Herries, Product Engineer and Cartographer, Esri conveys, ″Digital maps are pushed into our digital lives regularly. Our fundamental desire to know where things are, how to get there, what the weather is like … these are joined today by a desire to understand where problems or needs exist, and compare alternatives to solving them.”

Maps are becoming an indispensable part of our lives. They are becoming all pervasive. From better governance to more profitable businesses to enable the communities to live

happier lives, maps are enabling people to make more informed decisions and achieve more efficient outcomes.

As Guruprasad S, Director, Market Screening Solutions, Bosch rightly puts it, ″Map as a service is of utopian help, to public health and payers to look at population health management, seasonal diseases heat map and strengthens the focus of social determinants of health, for better healthcare delivery planning, focussed campaigns, targeted outreach programmes etc.”

The trend is not new: Maps are not new to mankind. Though the concept of ′democratization of maps has picked up recently, maps have been an integral part of the human history for thousands of years. From cave paintings to ancient maps of Babylon, Greece, and Asia, through the Age of Exploration, and on into the 21st century, people have created and used maps as essential tools to help them define, explain, and navigate their way through the world.

It is interesting to discover that the earliest maps were actually ′story maps. Cartographers acted as artists, as they painted pictures based on knowledge, memories, and fears of travelers. The maps so created, not only described the landscape, but also the events that had taken place within it. These beautiful pieces of work allowed travelers to identify routes while experiencing a story.

As human intelligence evolved, the power of visualizing location became clearer. With advancements in technology, maps took the form of digital roadmaps and permeated every household through smartphones.

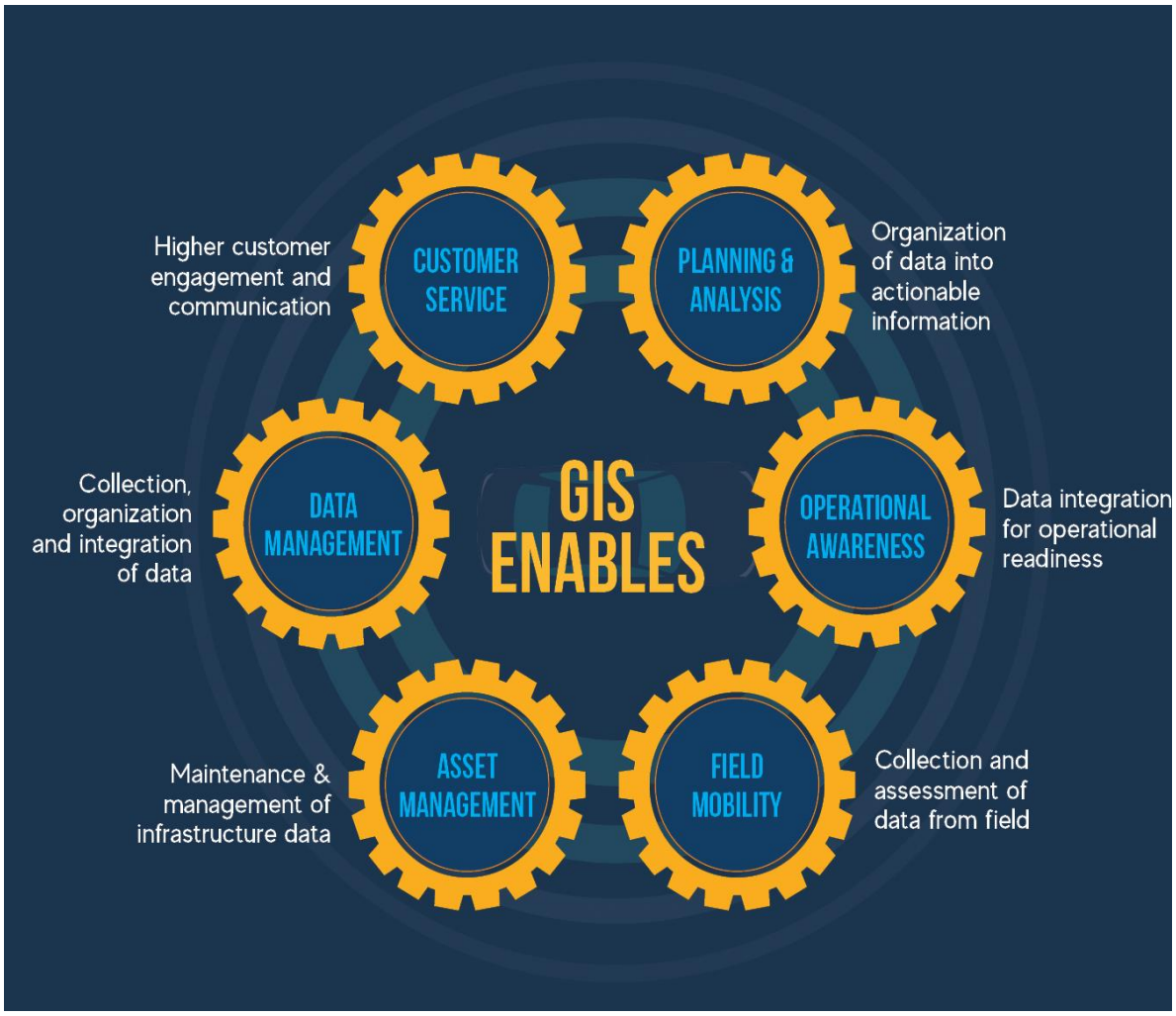
Mapping is a central function of Geographic Information Systems (GIS), which provide a visual interpretation of data. GIS analysts and specialists have emerged as the new gurus of cartographic science. Factors such as extensive use of GPS or Remote Sensing, globalization of data, use of internet, web mapping services, new software applications, have contributed greatly to the use of GIS and cartography for more and more applications every day.

The world is realizing that common problems cannot be solved unless intervention is made and intervention is impossible without visualization, and thus without ′maps′.

Web Mapping: In recent years there has been an explosion of mapping applications on the web such as Google Maps, and Live Maps. These websites give the public access to huge amounts of geographic data with an emphasis on aerial photography. Some of them, like Google Maps, expose an API that enable users to create custom applications. These vendors' applications offer street maps and aerial/satellite imagery that support such features as geocoding, searches, and routing functionality.

Some GIS applications also exist for publishing geographic information on the web that include MapInfo's MapXtreme, Intergraph's GeoMedia WebMap, ESRI's ArcIMS, ArcGIS Server, AutoDesk's Mapguide and the open source MapServer.

Maps in Governance: GIS-based mapping helps the governments achieve better governance as they are able to solve problems more quickly and efficiently. Governments use GIS and maps to improve their workflows and services to citizens. Visualizations through maps are used to accomplish better land-use planning, road and utility maintenance, emergency management, infrastructure assessment and development and property management. Local, state and federal governments have found



maps particularly useful in urban planning, including classification of land uses, zoning and subdivision planning, land acquisition, assessing the urban growth, environmental impact policy, and water quality management. Mapping can be of great help when it comes to managing urban growth and solving housing issues associated with the increasing population.

In the words of Herries, ″Maps help governments assess the needs of citizens, look for any spatial components of those needs or issues, and compare different plans of action to address those needs. For instance, consider the ″Clean Streets LA" initiative. The city of Los Angeles put maps to use, assessing every single street in the city with regard to how much trash or even dumping was present. The resulting data might have been kept out of the public′s eye, but instead, the city chose to address the issue of trash and illegal dumping in a very public way. Citizens can see maps of the entire city, and of course go look around their neighborhood, to see how clean or dirty their neighborhood is, schedule a pickup, or engage in other ways. The map helps create that engagement with citizens, to improve their lives specifically and the city overall."

GIS-based mapping helps the governments achieve better governance as they are able to solve problems more quickly and efficiently.

Maps in businesses: Organizations today are collecting data at every level of their business and in volumes that in the past was unimaginable. It is an accepted fact now that about 80% of all data has a spatial component.

According to Guruprasad, Bosh, ″It is estimated that roughly 2.5 quintillion bytes of data are generated per day. With this huge volume of data being churned out, business intelligence solutions have become a necessity rather than a luxury. In this highly data-intensive scenario, spatial analysis provides powerful ″where" perspectives and contextual insights. Being able to visualize the ″where" is invaluable for planning and enhances many business intelligence applications. As better insights deliver a better impetus for decision making, spatial analysis acts as a key differentiator for businesses today, enabling them to grow faster and smarter."

Traditionally, data would get presented to the user in the form of long reports, either with graphs and pie charts or in a spreadsheet format. Now, given the complex interrelationships of multidimensional data, visualization technology has become ineluctable for offering an accurate, high impact insight to business intelligence users.

Humans think visually, therefore spatially. Data gains immediate visual impact with the help of maps. This is more emphatically true for data with a spatial dimension. Maps best represent spatial phenomena or relationships such as flow or proximity, while also facilitating visualization of statistical measures for an area or region. In addition, maps allow multi-measure displays.

The importance of visualization in business can be better gauged from Peter Hawkins, Regional Director Digital Content, Asia Pacific, HERE, Singapore′s words, ″Visualisation on maps or any sort of special platform is critical. I think the old adage applies here that one picture can tell a thousand words. It is critical how people visualize and interact with maps. The maps and special data is going to get more complex, fast pace and near real time. And the way people consume and interact with it has to change. We have announced a stringent visualization strategy. It is going to become an important element in resolving a number of interface problems and challenges faced by the industry."

Spatial analysis is helping the industry to gain invaluable insights in stock delivery, store management, inventory management, marketing and sales.

As per Santiago Giraldo, Director, Product Marketing, Carto, ″Historically, location data was only available to highly trained specialists and used to produce static GIS maps depicting the past or current status, however, today location data and insights have become more accessible by turning the map into an interactive model, where all types of professionals can do sophisticated analysis on their own."

Today more people are using spatial data presented on maps to make faster, smarter decisions to improve business operations. ″While many early adopters have been in the financial sector, verticals like retail, telecommunications and real estate are also experimenting with and receiving benefits from spatial analysis based on maps today," adds Giraldo.

′Customer mapping enables organizations to identify the markets where they can find the highest concentration of the best potential customers. GIS allows efficient mapping and color-coded maps lead to easy identification of customer concentrations. These maps help in site-selection, which involves considering factors like income, community growth rate,

available workers, the physical features of the area such as roads, water, etc. and by using GIS, each of these factors can be layered on top of each other to identify the best possible location for a business.

For example, while considering relocation, a children′s clothing store could map the population of people with children in the targeted age group throughout the area under consideration. The data, once put into a GIS can generate maps wherein the highest concentration families with children are depicted using dark colors and those without using lighter colors. The final map so generated will highlight the ideal areas for the clothing store to be relocated.

Maps for citizens: Community development scales new heights when the power of maps is put to use. Maps are playing an increasingly important role in helping us create a safer, happier world. Be it leading a healthier life or producing higher quality food for feeding more mouths or having better preparedness for disasters, maps help in identifying threats and taking corrective actions on time.

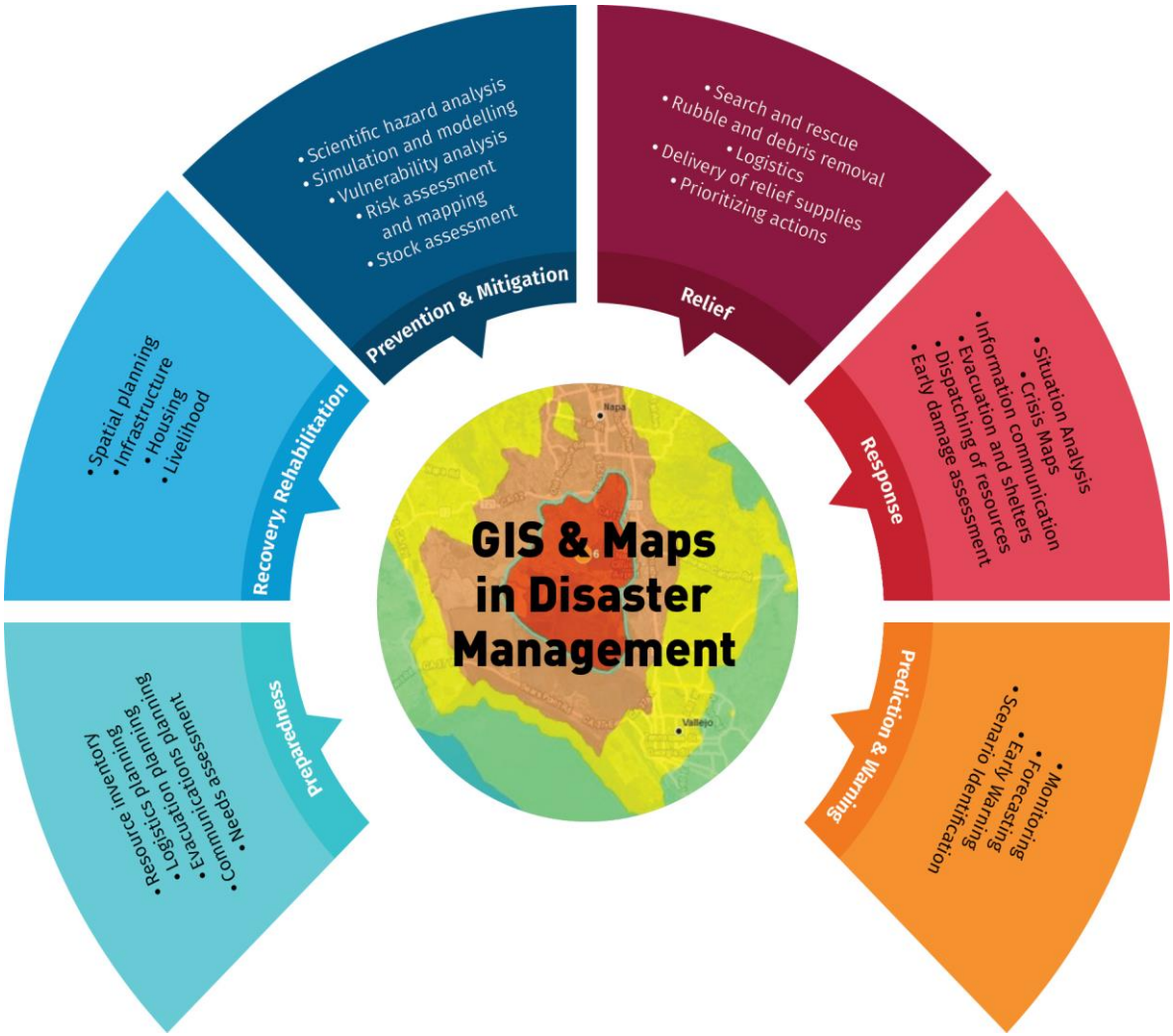
Both public and private sectors are developing innovative ways to harness data integration and spatial visualization power of GIS to provide enhanced healthcare services. Maps play a critical role in determining where and when to intervene, improving the quality of care, increasing accessibility of service and finding more cost-effective delivery modes.

Mapping allows healthcare professionals to identify health-related trends and target healing efforts based on those results more thoroughly. For instance, by integrating visualization in a Cancer Surveillance Program, healthcare professionals can visualize the locations of patients and determine if clusters of specific types of cancer are associated with similar working conditions or residential areas. Such studies often reveal important correlations, such as the association between people residing near heavily sprayed fields and higher incidences of prostate cancer among them. For years, healthcare professionals have relied on hand-drawn maps for identifying affected areas; things have become more systematic and accurate with maps generated by GIS.

With rising incidents of chronic diseases such as cancer, diabetes etc., mapping enables healthcare professionals to identify where certain diseases are more likely to or already have become prevalent and proactively begin implementing preventative strategies.

Using geography and other inputs, GIS can also help in identifying where the diseases are most likely to spread next. This kind of information can help in saving lives as it enables healthcare professionals to prepare in advance for the disease. Maps such as these play a significant role in the management of disease outbreaks as they help visualize where infected people live and the potential spread of the disease. Mapping can also be used to gain a better understanding of vaccination rates in different areas to determine which locations could be hit the hardest in case of a serious outbreak.

Use of maps can enable community leaders and developers to work more closely with hospitals to take larger steps in addressing national healthcare needs. The system can help identify which neighborhoods are in greater need of specific health services such as more rehab centers or senior care facilities. Analysis of patient demographic data can help answer these questions.



Maps for disaster management: Be it modeling through early warning systems or using decision support systems to understand which disaster is going to affect or is affecting which region the most, visualization achieved through GIS can help in mitigating the risks of a disaster to a great extent. As maps help in identifying disaster-prone areas, preparations can be better, efforts can be more directed and response can be faster.

For instance, landslides are one of the major disasters that occur in the hilly region. The disaster risks can be mitigated using maps. A "Landslide Hazard Map" includes "zonation showing the annual probability of landslide occurring throughout an area" (USGS). A landslide susceptibility map is a basic concept of landslide susceptibility and it includes the spatial distribution of factors related to the instability processes in order to determine zones of landslide-prone areas without any temporal implication.

This approach is useful for areas where it is difficult to secure enough information concerning the historical record of landslide events ranks the slope stability of an area in categories that range from stable to unstable. Susceptibility maps show where landslides may occur. This identification leads to better preparedness and thus lesser or no loss of lives.

Maps can be used to indicate vulnerability to different extents under different conditions. Areas likely to remain unaffected or remain comparatively safe could be identified and even alternate routes to shelters, camps, and important locations could be worked out.

Identification of vulnerable areas leads to smooth rescue and evacuation operations. Mapping of affected areas lead to better organization of rehabilitation and post-disaster reconstruction works could be properly organized.

More food to eat with maps: Use of GIS-based visualization to achieve higher quality food production is not a new phenomenon anymore.

Agricultural mapping is day by day becoming crucial for monitoring and management of soil and irrigation of farmlands. It is facilitating agricultural development and rural development. Accurate mapping of geographic and geologic features of farmlands is enabling scientists and farmers to create more effective and efficient farming techniques. As farmers are able to take more corrective actions in the form of better utilization of fertilizers, treating pest and weed infestations, protecting the natural resources etc., we are bestowed with more and higher quality food production.

While natural inputs in farming cannot be controlled, they can be better understood and managed with GIS applications. GIS can substantially help in effective crop yield estimates, soil amendment analyses and erosion identification and remediation. More accurate and reliable crop estimates help reduce uncertainty.

Mapping in agriculture helps farmers to achieve increased production and reduced costs by enabling better management of land resources. The risk of marginalization and vulnerability of small and marginal farmers, who constitute about 85% of farmers globally, also gets reduced.

Undoubtedly, the insight gleaned from the dimension of ′place opens doors to new learnings and potential patterns that enable the decision-makers to take better decisions and achieve more productive outcomes.

Exploring Global Change with GIS: Maps have traditionally been used to explore the Earth and to exploit its resources. GIS technology, as an expansion of cartographic science, has enhanced the efficiency and analytic power of traditional mapping. Now, as the scientific community recognizes the environmental consequences of human activity, GIS technology is becoming an essential tool in the effort to understand the process of global change. Various map and satellite information sources can combine in modes that simulate the interactions of complex natural systems.

Through a function known as visualization, a GIS can be used to produce images - not just maps, but drawings, animations, and other cartographic products. These images allow researchers to view their subjects in ways that literally never have been seen before. The images often are equally helpful in conveying the technical concepts of GIS study-subjects to non-scientists.

Adding the dimension of time: The condition of the Earth's surface, atmosphere, and subsurface can be examined by feeding satellite data into a GIS. GIS technology gives researchers the ability to examine the variations in Earth processes over days, months, and years.

As an example, the changes in vegetation through a growing season can be animated to determine when drought was most extensive in a particular region. The resulting graphic,

known as a normalized vegetation index, represents a rough measure of plant health. Working with two variables over time would then allow researchers to detect regional differences in the lag between a decline in rainfall and its effect on vegetation. GIS technology and the availability of digital data on regional and global scales enable such analyses. The satellite sensor output used to generate a vegetation graphic is produced by the Advanced Very High Resolution Radiometer (AVHRR). This sensor system detects the amounts of energy reflected from the Earth's surface across various bands of the spectrum for surface areas of about 1 square kilometer. The satellite sensor produces images of a particular location on the Earth twice a day. AVHRR is only one of many sensor systems used for Earth surface analysis

GIS and related technology will help greatly in the management and analysis of these large volumes of data, allowing for better understanding of terrestrial processes and better management of human activities to maintain world economic vitality and environmental quality.

Semantics and GIS: Tools and technologies emerging from the W3C's Semantic Web Activity are proving useful for data integration problems in information systems. Correspondingly, such technologies have been proposed as a means to facilitate interoperability and data reuse among GIS applications and also to enable new mechanisms for analysis.

Ontologies are a key component of this semantic approach as they allow a formal, machine-readable specification of the concepts and relationships in a given domain. This in turn allows a GIS to focus on the meaning of data rather than its syntax or structure. For example, reasoning that a land cover type classified as Deciduous Needle leaf Trees in one dataset is a specialization of land cover type Forest in another more roughly-classified dataset can help a GIS automatically merge the two datasets under the more general land cover classification. Very deep and comprehensive ontologies have been developed in areas related to GIS applications, for example the Hydrology Ontology developed by the Ordnance Survey in the United Kingdom. Also, simpler ontologies and semantic metadata standards are being proposed by the W3C Geo Incubator Group to represent geospatial data on the web.

Recent research results in this area can be seen in the International Conference on Geospatial Semantics and the Terra Cognita -- Directions to the Geospatial Semantic Web workshop at the International Semantic Web Conference.

GIS and Society: With the popularization of GIS in decision making, scholars have began to scrutinize the social implications of GIS. It has been argued that the production, distribution, utilization, and representation of geographic information are largely related with the social context. For example, some scholars are concerned that GIS may not be misused to harm the society. Other related topics include discussion on copyright, privacy, and censorship. A more optimistic social approach to GIS adoption is to use it as a tool for public participation.

Open Geospatial Consortium (OGC) standards: The Open Geospatial Consortium (OGC) is an international industry consortium of 334 companies, government agencies and universities participating in a consensus process to develop publicly available geo-processing specifications. Open interfaces and protocols defined by OpenGIS Specifications support interoperable solutions that "geo- enable" the Web, wireless and location-based services, and mainstream IT, and empower technology developers to make complex spatial information and services accessible and useful with all kinds of

applications. Open Geospatial Consortium (OGC) protocols include Web Map Service (WMS) and Web Feature Service (WFS).

GIS products are broken down by the OGC into two categories, based on how completely and accurately the software follows the OGC specifications. Compliant Products are software products that comply with OGC's OpenGIS Specifications. When a product has been tested and certified as compliant through the OGC Testing Program, the product is automatically registered as "compliant" on this site.

Implementing Products are software products that implement OpenGIS Specifications but have not yet passed a compliance test? Compliance tests are not available for all specifications. Developers can register their products as implementing draft or approved specifications, though OGC reserves the right to review and verify each entry.

Characteristics of the Geographic Information Systems Application: As mentioned earlier, GIS allows to combine data from various sources and various types (vector, raster, descriptive data). They also allow to conduct complex spatial analyses, data visualization and simulations of processes and phenomena occurring in our environment. Thanks to such wide possibilities, these systems have been used in many fields, including in forestry and agriculture, in ad- ministration, in environmental protection, in crisis management and rescue, supporting the work of many services such as: police, fire brigade, ambulance, transport, bank- ing, pharmacy, insurance, spatial planning and many others.

According to GŁOWACKI [2005], there is currently no field of knowledge related in any way to geography or Earth sciences, which are not related directly or indirectly to GIS.

Geographical Information Systems have found the greatest use in public administration offices. Their main task is to support the decision making of local or state authorities, allowing visualization of various processes. Thanks to them, it is possible to plan certain investments taking into account various parameters, including whether there are utility networks in a given place, whether a given plot has access to a public road, etc..

Performing all kinds of urban works, requires gather- ing and analysing a huge amount of data, including concerning terrain, its slope, use, insolation, land ownership, threats (erosive or flood), demography, accessibility of public facilities and many others. The Geographic Information Systems help to investigate the relations between these phenomena and to make the right decisions.

As another industry using geographic data systems, network management companies should be mentioned. Thanks to a coherent database, broad analyses supporting network management are possible, including: statistics on the use of individual network elements, estimation of business benefits, failure location, network performance test- ing, marketing research, network availability determination, process optimization.

These systems are also used with great success in agri- culture, taking into account the micro and macro economic approach. GIS software provides unlimited analytical possibilities in this area, aimed at optimizing the production cycle, the registration of agricultural plots, efficient and effective farm management, assessment of conditions for cultivation, yield forecasting or assessment of the correct- ness of the area's eligibility for subsidies as part of agricultural activities.

Geographic Information Systems help to optimize forest management activities in connection with the society needs and the economic pressure of the market. This system allows to analyse and visualize complex problems, which helps to make all decisions. It

allows, among others, to designate areas for afforestation, create thematic maps, visualize areas at risk on the maps, track and analyse changes in land use (tree felling, changing trees, etc.).

GIS class tools are also useful during spatial planning, including in the preparation of urban management plans, preparation of development plans, monitoring of changes in the development of space or modelling of change scenarios, eg. modelling of water reservoirs.

GIS software is a good tool supporting activities related to environmental management and its protection. As part of the management activities in the Silesian Voivodeship, a generally available database of bio- and geo-diversity was developed: BIOGEO-SILESIA, which allows locating objects of interest to the given person and environmental management, and GIS systems together with properly adapted methods allow to create a functional and efficient system for environmental protection activities.

The use of GIS has also proved to be very important in crisis management and rescue. The topographic database (TBD) is used for this purpose. Data contained in this database can be used to indicate the location of dangerous objects, planning the distribution of population centers, planning escape routes or commuting to places of disaster. The GIS class tools also enable conducting detailed analyses in the areas of potential threats. The use of interactive maps in institutions dealing with crisis management allows to improve work efficiency, ex. the police, fire brigade and ambulance services. For example, for the needs of the police, the National Police Information System was created, containing data on persons suspected of committing a crime or wanted people. Also in the State Fire Service, a geographical visualization system was implemented to improve decision-making processes and more effective rescue operations.

The Geographic Information System also allows performing various analyses to check the functioning of pub- lic transport. It allows, for example, to determine the frequency of buses and trains, which makes it easier for passengers to manage their time.

In tourism, these systems allow you to plan a route and assess the condition of tourist routes. An example of the GIS application in this industry is the geoportal of the Małopolska tourist routes.

The GIS class tools are also used for monitoring the state of cultural heritage, or in the study of historical greenery assumptions. This facilitates the using and management of archival information constituting the source material. Geographic Information Systems in this area are aimed at obtaining from various sources of spatial data about monuments, their conversion and integration, data visualization, their sharing and con- ducting possible analyses, and then monitoring of endangered objects and updating information about them.

GIS is also widely used in archeology. His main task is to manage newly discovered positions and artefacts. It allows to compile data related to the development of settlement, regarding terrain, altitude, soils, communication routes, hydrological networks, vegetation.

GIS Applications and Uses:

GIS in Mapping: Mapping is a central function of Geographic Information System, which provides a visual interpretation of data. GIS store data in database and then represent it visually in a mapped format. People from different professions use map to

communicate. It is not necessary to be a skilled cartographer to create maps. Google map, Bing map, Yahoo map are the best example for web based GIS mapping solution.

Telecom and Network services: GIS can be a great planning and decision making tool for telecom industries. GDi GISDATA enables wireless telecommunication organizations to incorporate geographic data in to the complex network design, planning, optimization, maintenance and activities. This technology allows telecom to enhance a variety of application like engineering application, customer relationship management and location based services.

Accident Analysis and Hot Spot Analysis: GIS can be used as a key tool to minimize accident hazard on roads, the existing road network has to be optimized and also the road safety measures have to be improved. This can be achieved by proper traffic management. By identifying the accident locations, remedial measures can be planned by the district administrations to minimize the accidents in different parts of the world. Rerouting design is also very convenient using GIS.

Urban Planning: GIS technology is used to analyze the urban growth and its direction of expansion, and to find suitable sites for further urban development. In order to identify the sites suitable for the urban growth, certain factors have to consider which is: land should have proper accessibility, land should be more or less flat, land should be vacant or having low usage value presently and it should have good supply of water.

Transportation Planning: GIS can be used in managing transportation and logistical problems. If transport department is planning for a new railway or a road route then this can be performed by adding environmental and topographical data into the GIS platform. This will easily output the best route for the transportation based on the criteria like flattest route, least damage to habitats and least disturbance from local people. GIS can also help in monitoring rail systems and road conditions.

Environmental Impact Analysis: EIA is an important policy initiative to conserve natural resources and environment. Many human activities produce potential adverse environmental effects which include the construction and operation of highways, rail roads, pipelines, airports, radioactive waste disposal and more. Environmental impact statements are usually required to contain specific information on the magnitude and characteristics of environmental impact. The EIA can be carried out efficiently by the help of GIS, by integrating various GIS layers, assessment of natural features can be performed.

Agricultural Applications: GIS can be used to create more effective and efficient farming techniques. It can also analyze soil data and to determine: what are the best crop to plant?, where they should go? how to maintain nutrition levels to best benefit crop to plant?. It is fully integrated and widely accepted for helping government agencies to manage programs that support farmers and protect the environment. This could increase food production in different parts of the world so the world food crisis could be avoided.

Disaster Management and Mitigation: Today a well-developed GIS systems are used to protect the environment. It has become an integrated, well developed and successful tool in disaster management and mitigation. GIS can help with risk management and analysis by displaying which areas are likely to be prone to natural or man-made disasters. When such disasters are identified, preventive measures can be developed.

Landslide Hazard Zonation using GIS: Landslide hazard zonation is the process of ranking different parts of an area according to the degrees of actual or potential hazard from landslides. The evaluation of landslide hazard is a complex task. It has become possible to efficiently collect, manipulate and integrate a variety of spatial data such as geological, structural, surface cover and slope characteristics of an area, which can be used for hazard zonation. The entire above said layer can well integrate using GIS and weighted analysis is also helpful to find Landslide prone area. By the help of GIS we can do risk assessment and can reduce the losses of life and property.

Determine land use/land cover changes: Land cover means the feature that is covering the barren surface .Land use means the area in the surface utilized for particular use. The role of GIS technology in land use and land cover applications is that we can determine land use/land cover changes in the different areas. Also it can detect and estimate the changes in the land use/ land cover pattern within time. It enables to find out sudden changes in land use and land cover either by natural forces or by other activities like deforestation.

Navigation (routing and scheduling): Web-based navigation maps encourage safe navigation in waterway. Ferry paths and shipping routes are identified for the better routing. ArcGIS supports safe navigation system and provides accurate topographic and hydrographic data. Recently DNR, s Coastal Resources Division began the task of locating, documenting, and cataloging these no historic wrecks with GIS. This division is providing public information that make citizens awareness of these vessel locations through web map. The web map will be regularly updated to keep the boating public informed of these coastal hazards to minimize risk of collision and injury.

Flood damage estimation: GIS helps to document the need for federal disaster relief funds, when appropriate and can be utilized by insurance agencies to assist in assessing monetary value of property loss. A local government need to map flooding risk areas for evaluate the flood potential level in the surrounding area. The damage can be well estimate and can be shown using digital maps .

Natural Resources Management: By the help of GIS technology the agricultural, water and forest resources can be well maintain and manage. Foresters can easily monitor forest condition. Agricultural land includes managing crop yield, monitoring crop rotation, and more. Water is one of the most essential constituents of the environment. GIS is used to analyze geographic distribution of water resources. They are interrelated, i.e. forest cover reduces the storm water runoff and tree canopy stores approximately 215,000 tons carbon. GIS is also used in afforestation.

GIS Solutions in Banking Sector: Today rapid development occurs in the banking sector. So it has become more market driven and market responsive. The success of this sector largely depends on the ability of a bank to provide customer and market driven services. GIS plays an important role providing planning, organizing and decision making.

Soil Mapping: Soil mapping provides resource information about an area. It helps in understanding soil suitability for various land use activities. It is essential for preventing environmental deterioration associated with misuse of land. GIS Helps to identify soil types in an area and to delineate soil boundaries. It is used for the identification and classification of soil. Soil map is widely used by the farmers in developed countries to retain soil nutrients and earn maximum yield.

GIS based Digital Taxation: In Local Governments, GIS is used to solve taxation problems. It is used to maximize the government income. For example, for engineering, building permits, city development and other municipal needs, GIS is used. Often the data collected and used by one agency or department can be used by another. Example Orhitec ltd can supply you with a system to manage property tax on a geographic basis that can work interactively with the municipal tax collection department. Using GIS we can develop a digital taxation system.

Land Information System: GIS based land acquisition management system will provide complete information about the land. Land acquisition managements is being used for the past 3 or 4 years only. It would help in assessment, payments for private land with owner details, tracking of land allotments and possessions identification and timely resolution of land acquisition related issues.

Surveying: Surveying is the measurement of location of objects on the earth′s surfaces. Land survey is measuring the distance and angles between different points on the earth surface. An increasing number of national and governments and regional organizations are using GNSS measurements. GNSS is used for topographic surveys where a centimeter level accuracy is provided. These data can be incorporated in the GIS system. GIS tools can be used to estimate area and also, digital maps can prepared.

Wetland Mapping: Wetlands contribute to a healthy environment and retain water during dry periods, thus keeping the water table high and relatively stable. During the flooding they act to reduce flood levels and to trap suspended solids and attached nutrients. GIS provide options for wetland mapping and design projects for wetland conservation quickly with the help of GIS. Integration with Remote Sensing data helps to complete wetland mapping on various scale. We can create a wetland digital data bank with spices information using GIS.

GIS Applications in Geology: Geologists use GIS in a various applications. The GIS is used to study geologic features, analyze soils and strata, assess seismic information, and or create three dimensional (3D) displays of geographic features. GIS can be also used to analyze rock information characteristics and identifying the best dam site location.

Detection of Coal Mine Fires: GIS technology is applied in the area of safe production of coal mine. Coal mine have developed an information management system, the administrators can monitor the safe production of coal mine and at the same time improve the abilities to make decisions. Fire happens frequently in coal mines. So it can assessed spontaneous combustion risk using GIS tools.(Kun Fang, GIS Network Analysis in Rescue of Coal Mine)

Assets Management and Maintenance: GIS helps organizations to gain efficiency even in the face of finite resources and the need to hold down the cost. Knowing the population at risk enables planners to determine where to allocate and locate resources more effectively. Operations and maintenance staff can deploy enterprise and mobile workforce. GIS build mobile applications that provide timely information in the field faster and more accurate work order processing.

GIS for Planning and Community Development: GIS helps us to better understand our world so we can meet global challenges. Today GIS technology is advancing rapidly, providing many new capabilities and innovations in planning. By applying known part of science and GIS to solve unknown part, that helps to enhance the quality of life and achieve a better future. Creating and applying GIS tools and knowledge allow us integrating geographic intelligence into how we think and behave.

GIS in Dairy Industry: Geographic Information System is used in a various application in the dairy industry, such as distribution of products, production rate, location of shops and their selling rate. These can be monitored by using GIS system. It can be also possible to understand the demand of milk and milk products in different region. GIS can prove to be effective tool for planning and decision making for any dairy industry. These advantages has added new vistas in the field of dairy farm and management.

Tourism Information System: GIS provides a valuable toolbox of techniques and technologies of wide applicability to the achievement of sustainable tourism development. This provide an ideal platform tools required to generate a better understanding, and can serve the needs of tourists. They will get all the information on click, measure distance, find hotels, restaurant and even navigate to their respective links. Information plays a vital role to tourists in planning their travel from one place to another, and success of tourism industry. This can bring many advantages for both tourist and tourism department.

Irrigation water management: Water availability for irrigation purposes for any area is vital for crop production in that region. It needs to be properly and efficiently managed for the proper utilization of water. To evaluate the irrigation performance, integrated use of satellite remote sensing and GIS assisted by ground information has been found to be efficient technique in spatial and time domain for identification of major crops and their conditions, and determination of their areal extent and yield. Irrigation requirements of crop were determined by considering the factors such as evapotranspiration, Net Irrigation Requirement, Field irrigation Requirement, Gross Irrigation Requirement, and month total volume of water required, by organizing them in GIS environment. (A. M. Chandra, S. K. Ghosh, Remote Sensing and Geographical Information System)

Fire equipment response distance analysis: GIS can be used to evaluate how far (as measured as via the street network) each portion of the street network is from a firehouse. This can be useful in evaluating the best location for a new firehouse or in determining how well the fire services cover particular areas for insurance ratings.(Himachal Pradesh, Development Report)

Worldwide Earthquake Information System: One of the most frightening and destructive phenomena of nature is the occurrence of an earthquake. There is a need to have knowledge regarding the trends in earthquake occurrence worldwide. A GIS based user interface system for querying on earthquake catalogue will be of great help to the earthquake engineers and seismologists in understanding the behavior pattern of earthquake in spatial and temporal domain. (A. M. Chandra, S. K. Ghosh Remote Sensing and Geographical Information System)

Volcanic Hazard Identification: Volcanic hazard to human life and environment include hot avalanches, hot particles gas clouds, lava flows and flooding. Potential volcanic hazard zone can be recognized by the characteristic historical records of volcanic activities, it can incorporate with GIS. Thus an impact assessment study on volcanic hazards deals with economic loss and loss of lives and property in densely populated

areas. The GIS based platforms enables us to find out the damage and rapid response against volcanic activities may helps to reduce the effect in terms of wealth and health of people.

Energy Use Tracking and Planning: GIS is a valuable tool that helps in the planning organizing and subsequent growth in the energy and utilities industries. The effective management of energy systems is a complex challenge. GIS has enormous potential for planning, design and maintenance of facility. Also it provide improved services and that too cost effectively.

GIS for Fisheries and Ocean Industries: GIS tools add value and the capability to ocean data. ArcGis is used to determine the spatial data for a fisheries assessment and management system. It is extensively used in the ocean industry area and we get accurate information regarding various commercial activities. To enhance minimizing cost for the fishing industry. Also it can determine the location of illegal fishing operations.

Monitor Rangeland Resources: GIS is a valuable tool used to monitor the changes of rangeland resource and for evaluating its impact on environment, livestock and wild life. Accurate observation and measurements are to be made to find out the changes in the rangeland conditions. GIS is also used to monitoring ecological and seasonal rangeland conditions .

Reservoir Site Selection: GIS is used to find a suitable site for the dam. GIS tries to find best location that respect to natural hazards like earthquake and volcanic eruption. For the finding of dam site selection the factors include economic factors, social considerations, engineering factors and environmental problems. This all information are layered in the GIS.

Forest Fire Hazard Zone Mapping: Forest is one of the important element of the nature. It plays an important role in the local climate. Forest fires caused extensive damage to our communities and environmental resource base. GIS can effectively use for the forest fire hazard zone mapping and also for the loss estimation. GIS also help to capture real time monitoring of fire prone areas. This is achieved by the help of GNSS and satellite Remote Sensing.

Pest Control and Management: Pest control helps in the agricultural production. Increasing in the rate of pest and weeds can lead to decrease in the crop production. Therefore GIS plays an important role to map out infested areas. This leads in the development of weed and pest management plan.

Traffic Density Studies: GIS can effectively use for the management of traffic problems. Today′s population along with the road traffic is increasing exponentially. The advantage of GIS make it an attractive option to be used to face the emerging traffic problems. By creating an extensive database that has all the traffic information such as speed data, road geometry, traffic flow and other spatial data and processing this information will provide us the graphical bigger picture for the traffic management.

Deforestation: Nowadays forest area is decreasing every year, due to different activities. GIS is used to indicate the degree of deforestation and vital causes for the deforestation process. GIS is used to monitor deforestation.

Space Utilization: GIS helps managers to organize and spatially visualize space and how it can best be used. Operational costs can be decreased by more efficiently using space including managing the moves of personal and assets as well as the storage materials. The

3D visualization in GIS platforms helps planers to create a feeling of experience like virtual walk inside the building and rooms before construction.

Desertification: Desertification is the land degradation due to climatic variations or human activities. GIS can provide the information of degraded land which can be managed by governmental agencies or by the communities themselves. GIS plays a vital role to reduce the desertification, the local governments are now widely depends on GIS for reducing desertification. With location based GIS analysis we can find where or which area is suitable for planting new vegetation and which area for the pipeline construction.

Disaster and Business Continuity Planning: Viewing building and locations assets along with emergency information such as weather patterns, and disaster zones, can provide organizations the required information to make better decision. GIS provide holistic understanding of facility status and performance, and brings together department, business systems, and data source for a comprehensive view into and throughout the organization. (Faisal I. Al-Shukri, GIS Utilization in Facility Management)

GIS for Business: GIS is also used for managing business information based on its location. GIS can keep a track of where the customers are located, site business, target marketing campaigns, and optimize sales territories and model retail spending patterns. Such an added advantage is provided by the GIS to enhance in making companies more competitive and successful. (Sita Mishra, GIS in Indian Retail Industry-A Strategic Tool)

Utilities: The GIS is used for different type of utilities like electricity, telecom and cooking gas on a daily basis and utilities to help them in mapping, in inventory systems, track maintenance, monitor regulatory compliance or model distribution analysis, transformer analysis and load analysis.(Gulzara Mamazhakypova)

Lease Property and Management: Revenue can be increased, operations and maintenance cost can be reduced when GIS is used to help manage space. Real estate and property managers can see and make queries about space including its availability, size and special constraints for the most cost effective use.

Development of Public Infrastructure Facilities: GIS has many uses and advantages in the field of facility management. GIS can be used by facility managers for space management, visualization and planning, emergency and disaster planning and response. It can be used throughout the life cycle of a facility from deciding where to build to space planning. Also it provides facilitate better planning and analysis.(Gulzara Mamazhakypova)

GIS for Drainage Problems in Tea Plantation Areas: Drainage problem in tea plantation differ widely because of its varied nature of physical conditions. Tea crop requires moisture at adequate levels all times of its growth. Any variation either excess or lack has a direct impact on the tea yield. This become greatly influenced the productivity of tea. Required some hydraulic design to solve this problem such as design of drains, checking the adequacy of the river and classification of water logged areas etc. GIS helps to reduce the water logging by establishing well developed plans.

Collection of Information about Geographic Features: GIS is not simply a computer system used for making maps. A map is simply the most common way of reporting information from a GIS database. So these systems are not only for creating maps but also most importantly the collection of information about the geographic features such as building, roads, pipes, streams, ponds and many more that are located in your community.

GIS for Public Health: GIS provides the cost effective tool for evaluating interventions and policies potentially affecting health outcomes. GIS analysis, environmental health data is also helpful in explaining disease patterns of relationships with social, institutional, technological and natural environment. It can be understand the complex spatial temporal relationship between environmental pollution and disease, and identifying exposures to environmental hazards. GIS can significantly add value to environmental and public health data.(The application of GIS in environmental health sciences: opportunities and limitations.)

Location Identification: This technique is used to find a location for a new retail outlet. It helps to find out what exists at a particular location. A location can be described in many ways, using, for instance, name of place, post code, or geographic reference such as longitude or latitude or X/Y.

Knowledge Based System for Defense Purpose: Regular analysis of terrain is essential for today′s fast paced battlefield. Conventional method of studying paper topographical maps is being replaced by use of maps in digital form to get terrain information. It is increasingly being used to derive terrain information from digital images. Which help to the selection of suitable sites for various military uses more accurate and faster. The uses of GIS provide information regarding the terrain features which can be useful for planning today′s war strategies.

Pipeline Route Selection: Pipeline route planning and selection is usually a complex task. GIS technology is faster, better and more efficient in this complex task. Accurate pipeline route selection brings about risk and cost reduction as well as better decision making process. GIS least cost path analysis have been effectively used to determine suitable oil and gas pipeline routes. An optimal route will minimize reduce economic loss and negative socio-environmental impacts.

Producing Mailing Labels for abutter Notification: Zoning board of appeals hearings or proposed action by a town or city require notifying abutting property owners. A GIS application for producing abutter mailing labels enables you to identify abutting property owners are in different ways. Once the properties are identified this kind of GIS applications can produce mailing labels and be integrated with a word processing ″mail merge ″capabilities.(http://www.mass.gov/)

Site Suitability for Waste Treatment Plant: There is an increasing amount of waste due to the over population growth. This has negative impact on the environment. With the help of GIS we can integrate various aspect layers in GIS and can identify which place is suitable for waste treatment plant. This process will reduce the time and it is cost effective. Also it enhances the accuracy. It provides a GIS analyst to identify a list of suitable dumping sites for further investigations. It also provides a digital bank for future monitoring program of the site.

Geologic Mapping: GIS is an effective tool in geological mapping. It becomes easy for surveyors to create 3D maps of any area with precise and desired scaling. The results provide accurate measurements, which helps in several field where geological map is required. This is cost effective and offers more accurate data, there by easing the scaling process when studying geologic mapping.

Environment: The GIS is used every day to help protect the environment. The environmental professional uses GIS to produce maps, inventory species, measure

environmental impact, or trace pollutants. The environmental applications for GIS are almost endless. It can be used to monitor the environment and analyze changes.(by S Farog Mostafa)

Infrastructure Development: Advancement and availability of technology has set a new mark for professionals in the infrastructure development area. Now more and more professionals are seeking help of these technologically smart and improved information systems like GIS for infrastructure development. Each and every phase of infrastructure life cycle is greatly affected and enhanced by the enrollment of GIS.

Coastal Development and Management: The coastal zone represents varied and highly productive ecosystem such as mangrove, coral reefs, see grasses and sand dunes. GIS could be generating data required for macro and micro level planning of coastal zone management. GIS could be used in creating baseline inventory of mapping and monitoring coastal resources, selecting sites for brackish water aquaculture, studying coastal land forms.

Crime Analysis: GIS is a necessary tool for crime mapping in law enforcement agencies worldwide. Crime mapping is a key component of crime analysis. Satellite images can display important information about criminal activities. The efficiency and the speed of the GIS analysis will increase the capabilities of crime fighting.

River Crossing Site Selection for Bridges: The important geotechnical consideration is the stability of slope leading down to and up from the water crossing. It is advisable to collect historical data on erosion and sedimentation. On the basis of these information asses the amount of river channel contraction, degree of curvature of river bend, nature of bed and bank materials including the flood flow and the flow depth, all these can be done in GIS within estimated time and accurately. This information has been often used for river crossing site selection for bridges.

Land Use Changes Associated with Open Cast Strip Mining: Mining is the back bone of the developing economy of any country. Mapping, monitoring and controlling the impact caused by the mining activities is necessary so as to understand the character and magnitude of these hazardous events in an area. The data required to understand the impact of mining from the environment is coming from different discipline, which need integration in order to arrive hazard map zonation.

Economic Development: GIS technology is a valuable tool used for the economic development. It helps in site selection, suitability analysis, and for finding the right sites to locate new business and grow existing ones. Within economic development, GIS is used to support the emerging trend of economic gardening, a new way to foster local and regional economic growth by existing small business in the community.(By Ahmed Abukhater,GIS for Planning and Community Development: Solving Global Challenges)

Locating Underground Pipes and Cables: Pipe line and cable location is essential for leak detection. It can be used to understand your water network, conducting repairs and adjustments, locating leaks known distance for correlating etc. Pipelines are continually monitored, check for leak detection and avoid the problem of geo hazards.

Coastal Vegetation Mapping and Conservation: Coastal vegetation like Mangroves are the protectors of coast from natural hazards like tsunami , so that the conservation of these vegetation are highly important. GIS enable us to map which are having higher density of vegetation and which area need more vegetated? Integration of these details to

coastal zone mapping helps to identify the area prone to coastal erosion and we can plant more vegetation to reduce coastal erosion.

Regional Planning: Every day, planners use Geographic Information System (GIS) technology to research, develop, implement, and monitor the progress of their plans. GIS provides planners, surveyors, and engineers with the tools they need to design and map their neighborhoods and cities. Planners have the technical expertise, political savvy, and fiscal understanding to transform a vision of tomorrow into a strategic action plan for today, and they use GIS to facilitate the decision-making process. (ESRI, GIS Solutions for Urban and Regional Planning)

GIS for Land Administration: In a number of countries, the separate functions of land administration are being drawn together through the creation of digital cadastral databases, with these database they can reuse land for suitable needs ,digital taxation and even utilities are also easily handle using these database.

Snow Cover Mapping and Runoff Prediction: Systematic, periodical and precise snow cover mapping supported by GIS technology, and the organization of the results in a snow cover information system forms the basis for a wide range of applications. On the practical side, these applications are related to the monitoring of seasonal and yearly alterations of the snow cover under the presently existing climatic conditions, to simulate and forecast runoff, to map the regional distribution of the water equivalent, and to document the recession process of the snow cover during the melting period in its relation to geological features.

GIS for Wildlife Management: Man made destruction such as habitat loss, pollution, invasive species introduction, and climate change, are all threats to wildlife health and biodiversity. GIS technology is an effective tool for managing, analyzing, and visualizing wildlife data to target areas where international management practices are needed and to monitor their effectiveness. GIS helps wildlife management professionals examine and envision.

GIS Applications in Major fields:

Geographic Information Systems as a Tool for Environmental Assessment: Geographic information systems (GISs) have become a standard tool for use in environmental assessment and analysis due to the complexity and volume of information now available. In the past few decades, an increased demand for the efficient storage, analysis, and display of environmental data has led to use of computers and the development of sophisticated information systems. GISs enable users to display and compare spatial data from a geographic location for a particular set of objectives, and may allow impact modeling. The combination of GISs with associated data sources, such as remote sensing imagery, is now common in environmental monitoring and assessment. The ability to manage voluminous sets of data from different origins, formats, and scales allows analysts to approach environmental studies in different manners (Silveira et al., 1996).

Rudimentary GISs were developed in the late 1960s, and by the mid-1970s were already being used for environmental impact analysis. The overlay technique, discussed in Chapter 6, was computerized in the early 1970s and first used for siting power lines and roads. Improvements in GISs enabled their use for environmental assessment and analysis (Haklay et al., 1998). The application of GISs to environmental analysis continues to grow.

Using a GIS as an environmental modeling tool allows modelers to incorporate database capabilities, data visualization, and analytical tools in a single integrated environment. However, while GISs are widely used as tools in environmental assessment, their use is largely limited to basic GIS functions such as map production, overlay, and buffering (Haklay et al., 1998). This use alone does not take full advantage of the spatial analysis and modeling capabilities of a GIS. Future applications of GISs in environmental assessment will continue to evolve from the simple storage and display of data to include more sophisticated data analysis and modeling capabilities to allow comparisons among alternative courses of action. An example might be evaluation of the compatibility of a proposed activity with the soils and vegetation at several possible project sites. While simple overlays may show the intersection of several elements, advanced GIS programs are able to evaluate and rank suitability for many factors simultaneously. The development of intelligent GISs to support spatial analysis decisions will play a large role in environmental research in the future (Silveira et al., 1996).

GIS provides a tool that is especially useful in complex modeling predictions. Current GISs manage data through four processes. Encoding is the process of creating digital abstractions of the real world, storage is the ability to effectively handle these data, analysis is the correlation of spatial data to variables, and finally, the results are shown through a display process. GISs also keep track of metadata, or ″data about the data.” For modelers to take full advantage of a GIS in complex modeling capabilities, the integration of the two systems must be tightly coupled (Karimi et al., 1996).

Although the use of GISs in environmental impact analysis provides many benefits, there are several factors that may limit their applicability. Many of these limitations are related to economics. A substantial amount of time and cost are required for compiling the necessary data, establishing a GIS, and analyzing the system's output. Adding to the cost, specialized personnel are required for the operation and maintenance of a GIS. Information in a GIS quickly becomes dated (″last year's numbers”), and the GIS overseer must be willing to commit to an ongoing, and often expensive, effort for data gathering and input. This is especially important if there has been a large-scale change to the ambient environment such as caused by a wildfire, faunal population shift, or suburban residential expansion. GIS software is subject to updates, reworks, viruses, and bugs, and GIS hardware is often expensive and delicate to maintain. When using a GIS in preparation for impact assessment, personnel need to be technically knowledgeable not only about the computer system but also the environmental issues it would address. The economic concerns may be particularly relevant in using a GIS for impact analysis because environmental impact studies are often conducted by private consultants operating in a highly cost-competitive market (Haklay et al., 1998).

In addition to economic limitations, there are other concerns with using GISs or other computer aids for impact analysis. The lack of data, the cost of obtaining such data, and their level of accuracy often reduces the applicability of GISs for low-cost, small-scale projects. Additionally, as with many highly technical systems, there is the danger of ″tunnel vision.” It is easy for the user to assume that all factors and considerations have been accounted for within the system. Consequently, users may overlook other factors that are essential to the local environment and not covered by the GIS data set being used. Similarly, as with the many expert-based tools, there is the danger that the user will view the system as a ″black box.” The system takes inputs and generates outputs; the reasoning process has been hidden away within the system, and the internal process may be unknown resulting in its potential shortcomings not being fully considered.

Furthermore, individual judgments and values have been internalized within the system's software. The environmental parameter sets contain ″facts" (actual data or sometimes estimates) gathered by various specialists. Choices concerning what information should be included within these knowledge bases are based upon the judgments of individuals. These choices will reflect individual and regional values as well as criteria related to the specialization of the experts involved. The use of computer systems does not allow these choices to be openly scrutinized by the user or reviewers; the information is stored away within the computer. Further, some data sets may contain sensitive spatial data whose public release is not allowed, such as the location of archaeological sites. These data are necessary to prepare the analysis, but should not be visible to observers without a need to know. Overall, the increased use of technology to process large amounts of data is establishing a barrier between the user and the process impact identification. The danger is that users will unquestioningly take expert system results and act on them without understanding the process and carefully considering the application of outputs (Morgan, 1998).

In summary, although the potential of GISs for environmental impact analyses is understood, actual application of GIS analytical capabilities continues to evolve. A GIS works well for a large, established federal location, such as a park or a research site, with a long-term mission commitment and a relatively stable environmental baseline. It does not work as well for programmatic analyses, proposals with scattered implementation sites, or agency actions proposed for areas with minimal environmental baseline information. Only a small number of agencies and consultants possess the full complement of skills and resources to perform analyses at this higher level. Broader use of this approach will require improvements within GIS as well as the development of a higher level of personnel expertise and significant reduction in the time and cost required to do so. These problems can be expected to be an especially significant constraint on the regular use of advanced GIS techniques, considering the stringent time and high costs that usually apply to environmental impact analysis. With improvements in these limiting factors, however, much of the impact assessment process could potentially be largely automated through advances such as use of universal local or regional databases available to all users, and standardized analytical tools developed specifically for this purpose. In time, GISs may be the best ally of the environmental impact professional.

How GIS is enabling the agricultural sector: GIS in agriculture is not a new phenomenon anymore. The agricultural sector is the mainstay of the rural Indian economy around which socio-economic privileges and deprivations revolve, and any change in its structure is likely to have a corresponding impact on the existing pattern of social equality. No strategy of economic reform can succeed without sustained and broad-based agricultural development, which is critical for raising living standards, alleviating poverty, assuring food security, generating a buoyant market for expansion of industry and services and making a substantial contribution to the national economic growth.

The future growth in agriculture must come from new technologies which are not only cost-effective but also in conformity with natural climatic regime of the country; technologies relevant to rain-fed areas specifically; continued genetic improvements for better seeds and yields; data improvements for better research, better results, and sustainable planning; bridging the gap between knowledge and practice; and judicious land use resource surveys, efficient management practices and sustainable use of natural resources.

Sustainable agricultural production depends on the judicious use of natural resources (soil, water, livestock, plant genetic, fisheries, forest, climate, rainfall, and topography) in an acceptable technology management under the prevailing socio-economic infrastructure. Technology plays an important role in the rapid economic growth and social transformation in developing countries.

Agricultural mapping: Technological innovations and geospatial technology help in creating a dynamic and competitive agriculture which is protective of the environment and capable of providing excellent nutrition to the people. While natural inputs in farming cannot be controlled, they can be better understood and managed with GIS applications. GIS can substantially help in effective crop yield estimates, soil amendment analyses and erosion identification and remediation. More accurate and reliable crop estimates help reduce uncertainty.

A central issue in agricultural development is the necessity to increase productivity, employment, and income of poor segments of the agricultural population, and by applying GIS in agriculture, this situation can be addressed. GIS tools and online web resources are helping farmers to conduct crop forecasting and manage their agriculture production by utilizing multispectral imagery collected by satellites. The ability of GIS to analyze and visualize agricultural environments and workflows has proven to be very beneficial to those involved in the farming industry. GIS has the capability to analyze soil data and determine which crops should be planted where and how to maintain soil nutrition so that the plants are best benefitted.

GIS in agriculture helps farmers to achieve increased production and reduced costs by enabling better management of land resources. The risk of marginalization and vulnerability of small and marginal farmers, who constitute about 85% of farmers globally, also gets reduced.

Agricultural Geographic Information Systems using Geomatics Technology enable the farmers to map and project current and future fluctuations in precipitation, temperature, crop output etc.

Agricultural mapping is day by day becoming crucial for monitoring and management of soil and irrigation of farmlands. It is facilitating agricultural development and rural development. Accurate mapping of geographic and geologic features of farmlands is enabling scientists and farmers to create more effective and efficient farming techniques. As farmers are able to take more corrective actions in the form of better utilization of fertilizers, treating pest and weed infestations, protecting the natural resources etc., we are bestowed with more and higher quality food production.

GIS in archaeology: As mentioned earlier, GIS is now very widely used amongst archaeologists and it also has increasing relevance to members of other historical disciplines. Many different types of data can be integrated into an archaeological GIS project, and many different forms of analysis appropriately applied to them. Common data types include:

- Background map data, taken from national mapping agencies or other sources.
- Digital Elevation Models (DEM) of terrain (more on which later).
- Aerial photographs of archaeological sites.
- Satellite images, used to display background geographic context, modern vegetation patterns, or to discover new sites (particularly in barren, desert locations).

- The results of geophysical surveys, such as resistivity, magnetometry, ground penetrating radar, etc. Field survey results, showing survey transects / sites and including their quantified contents. Excavation data recorded using Computer Aided Design (CAD) tools.
- Sites and monuments records, and other equivalents.
- Environmental data, such as soil maps, hydrology, climatic data, etc.

All of these and many other types of spatial data may be combined, and studied together in a GIS. GIS-literate archaeologists may then use various analytical methodologies to explore and test these data sets, commonly including:

- Viewsheds showing the visible terrain from a particular site.
- Predictive modelling of areas of archaeological sensitivity.
- Cost surfaces used to plot possible past travel routes through the landscape.
- Trend surfaces used to estimate the average state of a variable (such as artefact deposition) across a landscape. Spatial and attribute querying of data, and statistical analyses.
- Analysis of clusters, territories, and site catchments.
- Hydrological and palaeoenvironmental modelling.

GIS in Energy Utilization: Energy utilization refers to adopting new techniques of energy use. Natural resources can be saved by new means of energy utilization. Nowadays focus is being placed on implementing environmentally friendly treatments that will directly help by saving some amount of energy, which can be utilized in many ways in further treatments.

For implementing energy-saving policies the following points can be taken into consideration:

1. The technologies adapted in any field should be refined in such a way that maximum energy can be saved at the end of the process.
2. The techniques should be chosen such that they will enhance the efficiency of the process.
3. Energy should be saved and that energy may be used for further operations.
4. Renewable energy sources should be implemented or may be compulsory wherever they can be easily adoptable.
5. GISs are able to do such mapping as may be helpful for utilizing the energy outputs.
6. GISs can be helpful in locating such advanced tools for utilization.

The salient features of GIS in energy utilization can be divided into following categories:

1. Spatial DBMS (SDBMS);

2. GIS for collection of waste, storage of waste, and transport route optimization;

3. GIS for site selection (based on location, site area, distance);

4. decision support system and multicriteria analysis;

5. GIS for energy distribution;

6. Web GIS (real-time monitoring).

Spatial Database Management Systems

Additional capabilities of handling spatial data are embedded in SDBMSs. Storing, modeling, and ″querying the spatial data" (geographic data) are the key features of an SDBMS.An SDBMS stores all the location details of WTE conversion sites and energy sources sites, and the distance between the plant and the source is also stored as spatial data. Along with the spatial data, the SDBMS can also store attribute data, i.e., name of the plant, amount of energy production, etc. The attribute data can be assigned to the spatial data wherever they are needed. One can monitor all the statistics related to a particular project.

Geographic Information System for Collection of Waste, Storage of Waste, andTransport Route Optimization

Storage of Waste

Storage of waste is one of the major steps involved in solid waste management. There are several factors that are considered for placing bins in the city:

- space availability;
- road width;
- distance from house.

GIS can play a very important role in the selection of final locations for placing bins in a colony/locality in a city, as the weights for the above criteria can be assigned and subsequently the ArcMap built-in algorithm can be used for the final selection.

Collection of Waste: A large fraction of the total amount of solid waste management by any municipal authority is the collection of solid waste. Different categories and types of vehicles are used for collection, which depend on the type of collection bins and road width.

GIS can be used for optimal selection of routes for both collection and subsequent disposal of solid waste using the Network analysis tool of ArcMap.

The transport of solid waste from the collection site (where the solid waste is generated) to the destination site, i.e., where the solid waste is deposited, by vehicles is very crucial as the transportation of solid waste causes air pollution and lengthy routes can be costly. The routes can be optimized very effectively by using the Network analysis tool in the GIS. Network-based spatial analysis represents the real world, including all the road networks, speed restrictions, traffic, type of road, etc., so that the most feasible route, i.e., the shortest and safest route, to transport the solid waste can be planned.

In the process of transporting the waste from the collection systems to the disposal sites, aGIS-based optimal routing model can be adopted, which will incorporate minimum cost and distance of transportation. This model is based on various input parameters such as road network, population density, amount of waste generation, location of collection bins, etc.

For a planner, manually deciding the optimal route will be a most difficult task, as it involves many selection criteria. Application of the principles of GIS mainly focuses on an efficient and well-planned solid waste management scheme. Various route optimization models have been given by various authors, for example, Male et al. used

districting and routing for solid waste collection, while Clark et al. gave a system analytical approach. Pelms and Clark proposed a location model for optimal location allocation and Baetz adapted simulation modeling for optimal solid waste collection.

As a result, transportation will be cost effective. The methodology used for route optimization in a GIS is territorial analysis, GIS analysis, and route plotting. The database used for route optimization is existing maps, orthophotographs (aerial images), and satellite images. Fig. shows an architectural view of solid waste collection and transportation.

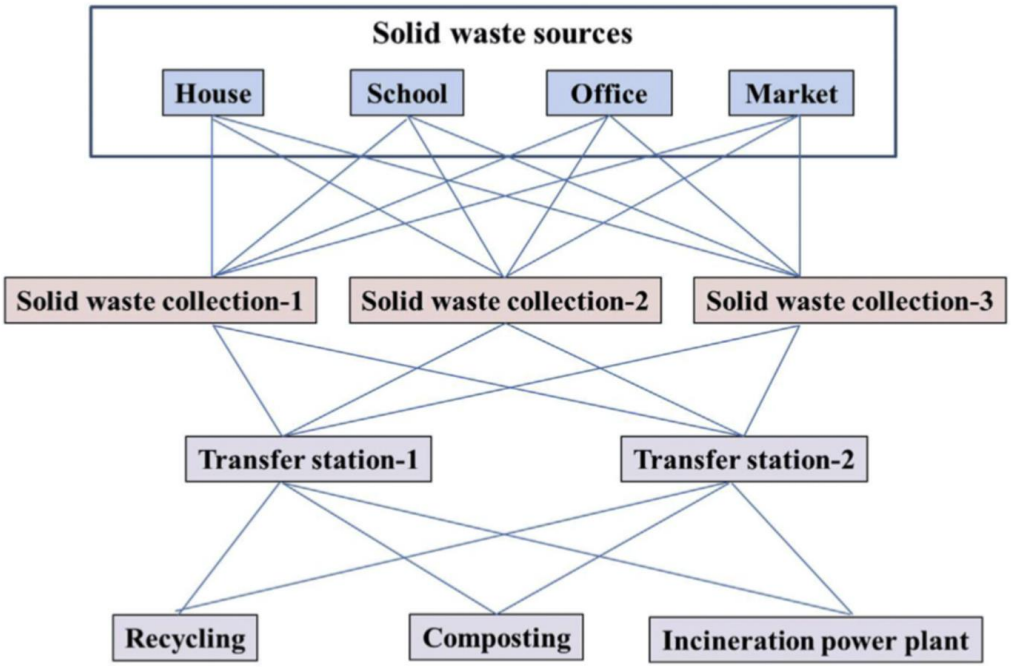


Fig. Architectural view of collection and transportation of solid waste.Modified from P.P.-J. Yang, J. Yan, Modeling urban design with energy performance.

Geographic Information Systems for Site Selection: There are various methods for management of municipal solid waste, such as land disposal, incineration, composting, dumping into the sea, etc., but land disposal is still one of the most followed practices in developing countries. Therefore finding the most suitable site for a landfill is a big challenge. There are various parameters, as discussed in next Section, that are used to select a suitable site.

Incinerators produce both noise and odor while in operation. So, planning to keep these incinerators within an urban area or highly populated area faces public disapproval.

Incinerators should be located away from populated areas. An environmental impact assessment should be done prior to the project. Different levels (from harmful to safer) of buffer zones can be designed through a GIS environment within the optimal radii from the location of the incinerator plant. Buffer zones are used for proximity analysis. Visualization of the flow direction of a pollutant can be shown in the GIS environment so that the waste treatment plant can be situated in the downstream direction. Distance from

urban centers, land use, and land cover are important criteria for selecting the best possible location of a waste treatment plant. At the same time, the distance between the energy source and the waste treatment plant should also be minimized to conserve energy during transportation of waste. After spatially locating the energy source, i.e., solid waste generation site or solid waste deposition site, a best possible site, fulfilling all the requirements, can be easily selected in the GIS platform.

Decision Support System and Multicriteria Analysis: An example of multicriteria analysis is site selection for a waste treatment plant. The following criteria need to be considered:

1. Nearby water bodies: avoid affecting a river.
2. Site accessibility by current road network: the plant should be as near as possible to avoid any additional construction cost of an access road.
3. Nearby residential or conserved areas (forest/wetlands): avoid zones to be protected.
4. Flood zones: Exclude from the site to avoid barriers.
5. Control of odors and noise.
6. Air pollutant dispersion: assess this by application of different models and visualization of results in the GIS platform.
7. Area of the site required.
8. Site topography: it should be properly lined with a uniform surface for any construction.
9. Soil type: select properly according to site location by considering cost factors.
10. Site stability: geotechnical properties like soil type, water content, porosity, permeability, nature of the soil, etc., should be checked to facilitate the construction work.
11. Geospatial analysis of satellite data using different tools such as remote sensing andGIS can ensure that all of the aforementioned criteria are followed before finalizing the site.

In addition to these issues, many other factors such as public acceptance and political decisions also play important roles in landfill site selection. The slope of the terrain should be evaluated for the landfill site. Those areas having slopes greater than 15% shall not be considered for the solid waste disposal site. GIS employs an analytical hierarchy process (AHP) for the multicriteria analysis, where by a weight is assigned to each criterion mentioned, based on its importance. The most optimal decision can be obtained from AHP.

The application of GIS in energy distribution is emerging as an efficient planning and decision-making tool. Visualization and spatial analysis make GIS a significant tool in energy distribution application. The optimal power line routing with the spatial information available is possible in the GIS environment. The physical address, i.e.,latitude and longitude, of the energy source, the energy transmission path, and the enduser can be spatially located with GPS, which would be the primary data for GIS analysis.In addition, the name of the consumer, energy consumption, etc., can be uploaded into the attribute data, which are directly linked to the respective consumer′s

physical address. This methodology results in the simulation of energy distribution in the real world in a better way. This database can be regularly updated in GIS and real-time data can be monitored.

Web GIS: With the development of Web GIS, the components of GIS are separated for farther distances. GIS users can access Web GIS anywhere around the globe with the help of a server. Real-time attribute data along with geographic data can be uploaded from anywhere in the world, as Web GIS is a client/server computing system. The uploaded data can be updated at regular time intervals for real-time monitoring. The total energy production, waste consumption, and other attribute information from a waste treatment plan can be seen by all the authorized clients. In addition, solid waste complaint monitoring and management can be done with Web GIS.

Using GIS for law enforcement: A Case study

Problem: In this age of diminishing resources, it is critical that public safety and law enforcement officials direct their efforts to areas that will produce the most benefit. In regards to traffic safety, developing a relationship between where officers are spending their time (citation locations) and where the public is exhibiting unsafe driving behavior (crash locations;Kim & Levine, 1996; Miaou, 2001) will assist law enforcement officials in optimizing their enforcement strategies.

Method: One mechanism that greatly assists public safety personnel in applying resources appropriately is the ability to investigate and visualize enforcement activities in conjunction with identified high risk areas. In 2005-2007, the CARE Research and Development Laboratory (CRDL) at the University of Alabama, through the development of the Motor Carrier Analysis Package (MAP), has developed an electronic citations (E-Citation) application and coupled it with an existing crash database analysis software called Critical Analysis and Reporting Environment (CARE) to develop a Geographical Information System (GIS) to display results spatially. This allows officers to use theGIS to map vehicle crash and traffic citation locations.

E-Citation programs allow officers to write and print tickets on laptops in their police cruiser, and transmit those tickets to a central server within the courts system. The initial pilot study for the E-Citation project was at a State ofAlabama Weigh Station. The Weigh Station is connected to the Alabama Office of Courts through a dedicated broad-band connection. The Weigh Station is further equipped with a high gain 802.11b wireless connection. Laptops in patrol cruisers are also equipped with 802.11b connections,CDPD cellular cards, and integrated Global Position System(GPS) units. Additionally, the laptops are equipped with a card insertion scanner. The scanner allows for the automatic collection of driver license data from licenses that use non-encrypted magnetic strips or barcodes. Currently all states except Georgia use non-encrypted data. Following the pilot study, the E-Citation application has been deployed to all enforcement units in the commercial vehicles unit of theAlabama Department of Public Safety. All data, including the GPS data, is transferred to a central repository.Fig. 1 depicts the E-Citation process. This electronic process has proved to be a major improvement in both accuracy and efficiency for the officers using this program.

The CARE application provides ad hoc statistical analysis on static sets of categorical data. CARE was originally designed to analyze vehicle crash data, however, most of its techniques are applicable to any type of categorical data. The application provides analysis techniques including frequency distributions, cross-tabulations, crash rates per population size(ACT), various techniques for location analysis, and information mining

capabilities.Using data from the E-Citation application, in conjunction with CARE and GIS mapping technologies, the MAP program allows officers an online portal to access numerous safety-related variables. The online portal allows officers to view tickets written, statistically analyze crash and ticket data, and with the GIS, map citation and crash location data.

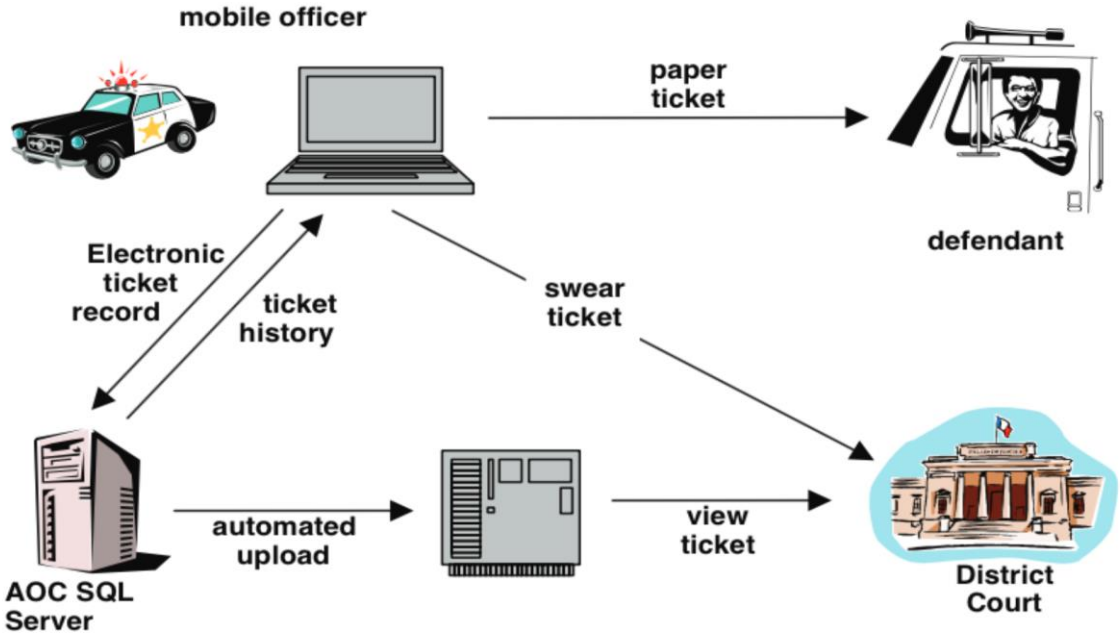


Fig. 1: E-Citation.

Results: Fig. 2 illustrates how MAP can help align enforcement activities to increase public safety. In Fig. 2, the main North/South roadway displays a heightened enforcement effort as depicted by the citations issued. The East/West roadway, however, is experiencing the larger number of crashes, making it a candidate for increased enforcement.By using the GIS tools, officers can simultaneously map locations of crashes and locations of tickets written. By performing analysis on this data, officers can get a better understanding of where problem areas are occurring, and better utilize resources.

In addition to connectivity to crash data, augmenting theE-Citation application with GPS information provides law enforcement officials integrated access to the rich process-ing capabilities of GIS applications to a wide range of data(Roche, 2000) including drivers license data, vehicle registrations, driver citation history, and previous jail records. Adding GPS coordinates to this data allows safety officials to view, for example, spatial trends of citations, historical migration of problem areas as noted by citation, and spatial analysis of citation location to defendant address. In Alabama, 8,000 users apply this process and it has been credited with significantly decreasing the time needed by law enforcement officers in solving specific crimes.

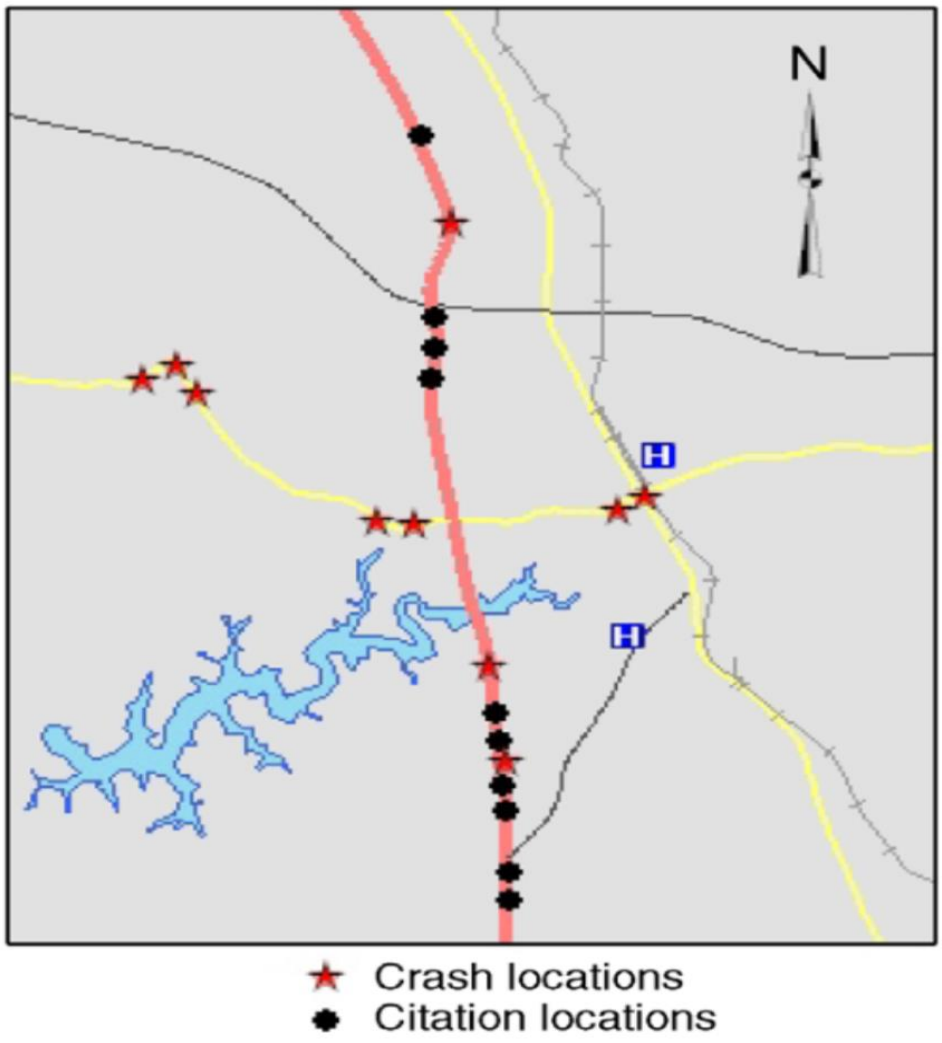


Fig. 2 Enforcement activity versus crash locations.

Summary: The integration of GIS technologies, E-Citation, MAP, and the CARE application, are having a positive impact on traffic safety in the state of Alabama. Further, additional efforts to equip public safety officials with GPS/GIS capabilities are expected to have a considerable positive impact on Alabama homeland security.

GIS in Mining : According to the regulations [Rozporządzenie ... 2015; Ustawa ... 2011] it is the entrepreneur's responsibility to ensure safety in mining plant operations, ensuring rational deposit management and environmental protection. An inseparable element of mining operations, starting from exploration and reconnaissance of the deposit, to liquidating a mining plant, is the measurement and geological documentation. Its basic ingredient is the mining map. According to the standard [PN-G-09000-1], mining map is ″a cartographic document prepared by authorized persons, presenting the situation and relief, mining excavations situation, geological situation, prepared by geometric projections or a mapping method, intended for mining operations". This document is to ensure proper and safe operation of mining plant operations [PN-G-09000-1]. Techno-logical progress related directly to the creation of this type of documents concerned the

maintenance of the map in numerical form and falls on the period after 1995. The result of this are publications and presentations at conferences. An example of this is the Scientific and Technical Conference that took place in October 1996 in Krakow. At the time, the first attempts to create a numerical mining map were carried out using programs operating in the Auto-CAD environment, eg. the Draw program, GEOLISP or in the MicroStation environment, e.g. the LC MAPA program.

Programs and IT systems were also created, which main task was to support works in the area of mining area protection.

The Silesian University of Technology has created programs that allow forecasting the impact of mining operations on the surface. The first of them was already developed in 1971 [DRZĘŹLA 1971]. For many years, about 24 programs have been developed, which have been gradually improved and which have gained great popularity in industry, being the basic tool for the work of measuring departments. From 1978, also at the Silesian University of Technology [BIAŁEK 2003] began to develop his programs. The effect of these works (period after 1986) was a series of programs enabling:

- creating, changing and visualizing input data describing exploitation, calculation points (objects), graphic elements constituting the background for contours of operation and contours of calculated deformation indices (programs integrating with the AutoCad); calculating the deformation of the mining area;
- determining the parameters of the theory based on the results of measurements; determining the size of protective pillars;
- calculating the state of stress and rock strength in order to assess the threat of rock bursts;
- analysis of seismic activity and its forecasting.

In AGH University of Science and Technology at the Department of Mining Surveying and Environmental Engineering, a system called SIOTG (Mining Area Information System) was created. Its main functions are:

- gathering information about the mining area and its development;
- collecting information on mining exploitation carried out and planned and its consequences;
- prediction of deformation of terrain surface and rock mass and determination of the risk level of cubic, linear and special objects;
- predicting hydrological and soil changes;
- graphic presentation of the mining area condition and its threat for different periods and variants of planned exploitation;
- estimating the extent of mining damage and choosing the optimal exploitation options.

As emphasized by the authors of the work [POPIOŁEK et al. 1996], ″the main function of the Mining Area Information System is to create a database of facilities and terrain, which is the basis for activities to protect against the negative effects of mining operations”.

Due to the huge amount of data that is collected and analysed in the surveying and geological departments, in addition to keeping the map in numerical form, it is needed to use Geographic Information Systems in mining plants. First of all, their task is to shorten the time of information searching and to analyse a lot of data from different sources. The base of the system is to be a relational data- base. Already at that time, it was recognized

that programs constituting such a system should enable the collection, introduction, maintenance, updating, processing and modi- fication of data constituting the content of the database.

In 2007, the implementation of an integrated deposit management system was started at Lubelski Węgiel Bogdanka. The basis of the system was a numerical map made in the MicroStation environment, using the SoftMine KWK Map application-ultimately, the basis for the GIS type system. Also in BOT KWB ″Turów" S.A., started to work about the so-called Mining Information System (Górniczy System Informatyczny – GSI). This task began with the implementation in 1998 of a numerical digital 3D map covering the mining area and other area, which together with the relational database of Mining Information System (BD-GSI) was the basic element of GSI.

The next step towards Geographic Information Systems was the creation of a numerical model of the deposit. An example is the Numerical Model of the deposit pre- pared in Kompania Węglowa S.A., for which an architecture based on a package of engineering applications was used: AutoCad Civil 3D, Oracle Spatial, EDBJ, GEONET and the GEOLISP numerical map service system.

Its task, apart from facilitating the preparation of geo- logical and metrological documentation, was to increase the efficiency and quality of mining planning, because it enabled:
fast and relatively easy access to collected data;

- fast information exchange by electronic way;
- performing multivariate analyses of a given phenomenon;
- simulation of selected solutions;
- calculation of deposit, loss and exploitation resources;
- planning of excavations providing access to deposits and operational excavations, taking into account all spatial data;
- printing of mining and surface maps at any scale depending on current needs;
- generating any profiles and sections;
- visualization of planned mining works

The result of this work was the Fusion Middleware SOA Suite software from Oracle, which is a tool used to build a numerical model of the deposit. The system includes the following programs: AutoCad Civil 3D, Oracle Spatial, EDBJ-OPN, GEONET and GEOLISP. This system can be considered a GIS class system. Over the next years, other GIS rank systems appeared. An example could be the first Land Information System implemented in KGHM Polska Miedź, which covered the entire area of the Company. The system structure included several subsystems such as: cadastral, topography, land deformation, environmental protection, mining damage .

An attempt to create a land information system was also made at the Department of Geology and Geophysics in Central Mining Institute. Data were organized in the form of vector and raster sets as well as descriptive information (thematic layers) constituting one issue, eg information on boundaries of mining areas, location of tremors, shallow exploitation, planned exploitation, etc. The three-dimensional model of excavations was also created in the Wieliczka Salt Mine. It was created to improve the mine traffic safety management conditions. Enriched with geological information and after connecting geometric objects with a relational database, it became the basis of the GIS type system.

Currently, there is a wide range of GIS software on the market that can support the mining industry (including ArcGIS, QGIS). These systems are also successfully used in underground and open-pit mines. They provide opportunities for, among others, visualization, modeling, database management, resource calculation, mine design or mining project planning. In mining enterprises, GIS are used, inter alia, to identify areas for exploration of resources, assessment of the impact of activities on the environment, planning for reclamation and waste management.

Using the ArcGIS program, ŚWITOŃ [2013] developed a database of graphic and descriptive data for the Thorez mine in the Wałbrzych Coal Basin. The database thus created allowed the author to conduct various spatial analyses, both in 2D and 3D. The GIS class system is used in the management of various types of rock raw materials, using for this purpose available documentation of the characteristics of deposits, methods of development, use and also ways to manage tchem. It is possible to use Geographical Information Systems also for monitoring, prediction and assessing the impact of mining tremors on building structures, as well as analysis of the effects of induced seismicity on building structures located on the surface.

Summary: Until recently, geographical space was described by means of maps. Technological development which took place in the first half of the 20th century allowed for significant acceleration and improvement of this process. The emergence of Geographic Information Systems has brought tools that easily allow to collect, verify, update, process, analyse and present in any form all the data collected in the system. Data ordered in a thematic manner form a single entity, related elements. This is done in a logical way based on the spatial relationships that occur between them. A characteristic feature of GIS is the ability to combine data of various types from different sources (data in vector, raster or descriptive form). Thanks to such wide possibilities, spatial information systems have been used in many areas of life.

The article presents the main areas of GIS utilization, with particular emphasis on the mining industry. Analysis of the available literature allowed the authors to demonstrate a wide spectrum of the use of such systems, ranging from administration, through urban planning, transport, forestry and agriculture, crisis management and rescue, ending with tourism and historical sciences. They analysed in detail the process of adapting these systems to the needs of mining enterprises, in terms of ensuring safety in mining plant operations, rational deposit management and environmental protection.

Taking all this into account, it seems unimaginable nowadays to manage space efficiently without GIS systems. Continuous improvement of the GIS class software may indicate that the application of these systems will be increasing and will affect many different areas of life.

MODULE-III

EMERGING TECHNOLOGIES AND APPLICATIONS IN GIS

MODULE-III: EMERGING TECHNOLOGIES AND APPLICATIONS IN GIS

Introduction: The term ″emerging technology" has been growing in popularity, particularly in the IT and academic world. However, emerging technology is relative as someone may see a technology as emerging, and others may not see it the same way. Additionally, this term takes on different meanings depending on the industry. For example, professionals in IT will view it drastically different than someone immersed in social media or medicine.

So what is emerging technology? While there is no universal definition of emerging technology, BusinessDictionary.com defines the concept as a new technology that is currently being developed or will be developed within the next five to ten years. Finally, this term applies to technologies that are currently creating or will create lasting economic or social effects.

Examples of Emerging Technology*:*

For a technology to be classified as emerging, it is characterized by rapid growth, impact, radical novelty, coherence, and, sometimes, uncertainty and ambiguity.

Examples of emerging technology can include:

- Artificial intelligence (AI)
- Gene therapy
- 3D printing
- Nanotechnology
- Cancer vaccines
- In vitro meat
- Medical field advancements
- Robotics
- Stem-cell therapy
- Distributed ledger technology
- And more

Each of these emerging technologies has the potential to create a significant competitive advantage for businesses in the near future. For example, artificial intelligence can be used in many different industries, including IT, medicine, finance, and more. This technology is making our smartphones smarter, providing deeper, more valuable insight into data, and making cloud-based tools more efficient. In terms of impact, this technology has the power to change the way we work.

AI is just one example of emerging technology. The global positioning system (GPS) is another notable example of new technology. We use it in every part of our lives. When we get into our cars, an aircraft, or even the local commuter train, GPS plays an important role. It not only gets us where we want to go, but it also provides information that keeps us safe by tracking the movements of other vehicles and providing accurate time and distance information.

Consider also MP3s, a technology that has eliminated the need to store vast amounts of physical media in our homes. Medical prosthetics have evolved to benefit our returning wounded servicemen and women. These advancements have created miniaturization and lighter materials that are easier to produce and are more affordable. Each of these new

technologies has transformed the way we live, and as more continue to emerge, our world will continue to change.

The Importance of Emerging Technology: Emerging technology can change the way we do business, making our world smarter, more efficient, and safer. While the invention of the computer, telephone, and internet has transformed the way we communicate with each other and how we do business, emerging technology seeks to further those advancements to further benefit both businesses and citizens.

In using these emerging technologies, not only can we find a better way to do business, but we can also create a safer, healthier world. For example, the US Department of Transportation is currently looking into vehicle-to-vehicle communication to help drivers communicate with each other and warn of hazardous road conditions. They hope this technology will reduce the number of car accidents on US roads. In the medical world, emerging technologies can help diagnose illness faster or help cancer patients receive better care. Finally, many new technologies are being used for environmental conservation. We can now use technology to create eco-friendly automobiles, beauty products, light bulbs, cleaning products, and more.

Harnessing the power of emerging technology can allow us to drive economic growth and gain valuable insight into how to make our world a safer, healthier, and more efficient place.

Definition of Emerging Technologies (ET): There is no widely agreed-upon definition of "emerging technologies." Very few articles provide a clear scope and complete definition for ET, and searching for an ET definition using a search engine does not return much information. Day and Schoemaker (2000) and Srinivasan (2008) state that ETs are science-based innovations with the potential to create a new industry or transform an existing one. For example, record label companies and the DVD market were destroyed because of the emerging Apple store and the iPod. The use of the word "science" means that ETs are produced from the collaboration of research and development, as most ETs begin as a conceptual research idea before they are created and developed. The Business Dictionary defines ET as "new technologies that are currently developing or will be developed over the next five to ten years, and which will substantially alter the business and social environment" (www.businessdictionary.com). This definition considers new technology as ET, which is not entirely accurate. This is one of the main misconceptions about ET. Technology can still be considered emerging in one context even though it has been considered established in another. The context here is related to place, domain, or application.

For example, Radio Frequency Identification (RFID) is not considered emerging in developed countries, whereas it is described as an ET in other poor and developing countries in the world where the Internet and communication technology infrastructures are still poor. Geographic information systems are considered established tools in the real estate and agriculture industries, but they are still considered to be emerging in the teaching of K-12 geography (Doering & Veletsianos, 2007). The Web was invented in 1990—1991 so it not labeled as an ET. However, various uses of the Web in different applications can make it an ET. This has been recently labeled Web 2.0 and Web 3.0, or the second and third generations of the Web. For example, Twitter, Facebook, and YouTube are ETs for journalists and the media. They have caused revolutions in Arabic countries, demonstrating how ET can change the social environment as defined by the Business Dictionary.

Miller et al. (2005) stated: A technology is still emerging if it is not yet a "must-have." For example, a few years ago email was an optional technology. In fact, it was limited in its effectiveness as a communication tool when only some people in an organization had regular access to it. Today, it is a must-have, must-use technology for most people in most organizations. In this sense, a technology can be a standard expectation in the commercial or business world, while still being considered as "emerging" in the education sector. (p. 6)

This definition focuses on the usage of technology and the extent to which it is widespread in a particular context or domain. This also conforms to Daniel et al.'s (1998) view of ET as something that is commercially available but not common or something that could become commercially available within the next five years. This definition implies that technology does not need to be new to be considered an ET (Vine, 2002). Rather, technology is considered emerging if it is not widely available in the market and used by people. In the project titled "Ethical Issues of Emerging ICT Applications (ETICA)," funded by the European Commission, Stahl (2011) studied the ethical implications associated with emerging technologies. He defined ET as technologies that have the potential to gain social relevance within the next 10 to 15 years. He adds that this means they are not only currently at an early stage in their development process, but they have already moved beyond the purely conceptual stage. The Business Dictionary definition of ET specifies that technology is considered emerging for the first 5 to 10 years of its lifecycle, whereas Stahl (2011) states that technology is emerging for the first 10 to 15 years. This is another misconception about specifying a range of time in a technology's lifecycle to determine if a technology is emerging. For example, virtual worlds were described as an ET in the mid-1990s (Dede, 1996). However, virtual worlds are still described as an ET. For example, Second Life (a 3D virtual world) is labeled as an ET (Barnetta, 2009). This means that the life of a technology can exceed 15 years and the technology can still be considered emerging, as is Second Life, which is still in its early revolution and is being discovered by many business models.

To sum up, ETs are not necessarily new. Technology is labeled as emerging in a particular context (domain, place, or application) but can be established elsewhere. Technology is also considered emerging when it is not widespread in a particular context. ET has no limited or fixed life. Technology is defined as emerging when it causes a radical change to business, industry, or society.

Attributes of Emerging Technology: The following can be considered as the attributes of the emerging technology:

(i) radical novelty,
(ii) relatively fast growth,
(iii) coherence,
(iv) prominent impact, and
(v) uncertainty and ambiguity

Radical novelty: Emerging technologies are radically novel, i.e. they fulfill a given function by using a different basic principle as compared to what was used before to achieve a similar purpose. Publications and patents are of limited use in assessing radical novelty in contemporary technology. In contrast, news articles, editorials, review and perspective articles in professional as well as academic journals represent valuable sources, providing participant perspectives on if and why a technology is viewed as

radically novel. These documents may also provide an understanding of the basic principles underpinning the examined technology.

In contrast, in retrospective analyses citation and co-word analyses can be particularly effective for identifying radical novelty. Relatively large amounts of data can be exploited to map the cognitive networks of a knowledge domain over time. Citation analysis builds on citation patterns among documents to generate a network in which nodes are documents and links between nodes represent (i) a direct citation between two documents (direct citation analysis) (Garfield et al., 1964), (ii) the extent to which two documents are cited by the same documents (co-citation analysis) (Small, 1973), or (iii) to what extent two documents cite the same set of documents (bibliographic coupling) (Kessler, 1963). Co-word analysis instead exploits the text of documents to create a network of keywords (or key phrases) that are linked according to the text to which they co-occur across the set of selected documents.

On the premise that clusters of documents or words in these networks represent different knowledge areas of a domain or different literatures on which the domain builds, several studies have considered the appearance of clusters not previously present in the network as a signal of novelty (e.g. ´Erdi et al., 2012; Kajikawa and Takeda, 2008). Others dispute this interpretation. Given the continuous evolution of science and technology, one is unlikely to find a cluster again in subsequent annual networks so the percentage of clusters that would qualify as newly appearing tends to be relatively high. For this reason, additional criteria have been suggested such as the appearance of new clusters that also link otherwise weakly connected (e.g. betweenness centrality) clusters, that form around documents that are highly cited by recent documents and the citations of which also are mostly from recent documents (Breitzman and Thomas, 2015), or that cite more recent clusters as identified by the (Salton) similarity of their references.

Small et al. (2014) have recently proposed a hybrid approach based on a combination of direct citation and co-citation models as applied to publication data. This approach is particularly focused on the detection of novelty, which is defined in terms of clusters that are new to the co-citation model — that is, clusters with limited overlap with the cited documents included in clusters in previous years (Boyack et al., 2014) — as well as to a parallel direct citation model. By combining bibliographic coupling, co-word analysis, and direct citation analysis, Gl¨anzel and Thijs (2012) instead defined novelty (namely emerging topics) as three cases of clusters: those that show exceptional growth, those that are completely new but with their roots in other clusters, or already existing ones that exhibit a topic shift. Yan (2014) combined co-word analysis with Natural Language Process (NLP) approaches (topic modelling). Emergence, as reflected in novelty, is then associated with the appearance of topics that are not a close variation of other topics calculated on the basis of the Jenson-Shannon Divergence.

Specifically, a topic i appearing at time tis considered to be emerging if it has no predecessors and none of the identified topics transforms into topic i at t+1. A different perspective is provided by Scharnhorst and Garfield (2010) who extended the analysis of historiographs (based on direct citations) to trace the extent to which publications move across fields as they receive citations from new fields (namely fi′eld mobility′). Assuming that these publications are associated with a basic principle used for technological applications, this approach enables one to identify which fields may be using a different knowledge base and thus in which fields radically novel technologies are potentially emerging. However, this requires a priori knowledge of the basic principle and the set of documents associated with it.

Research in scientometrics has also focused on the development of techniques to expand the ’local ’(domain) perspective that citation or text-based approaches may provide. This effort has generated a number of overlay mapping techniques (for an overview see Rotolo et al., 2014), which in turn may be particularly well suited to detecting radical novelty. The basic idea is to project a given set of documents (e.g. publications associated with a research domain) on a basemap through the use of an overlay. The basemap can represent the ’global ’science structure at the level of the scientific discipline (ISI Web of Science (WoS) subject categories) (e.g. Rafols et al., 2010), journal (e.g. Leydesdorff et al., 2013), Medical Subject Headings (MeSH) (Leydesdorff et al., 2012), or the technological structure at the level of patent classes (e.g. Kay et al., 2014; Leydesdorff et al., 2014). Once the set of documents (publications or patents) associated with a given domain has been identified, the projection of these documents over different time slices on the global map of science or technology may reveal the increasing involvement of new scientific or technological areas. This may suggest that new knowledge areas are being accessed to conduct research, and thus that potentially different basic principles are drawn upon to achieve a given purpose.

Among the studies within the ′indicators and trends group of techniques, Moed (2010) proposed the source normalised impact per paper (SNIP) indicator for the evaluation of journals′ impact and claims it is relevant for identifying emerging technologies. This indicator is defined as the ratio between the journal′s raw impact per paper (number of citations in the year of analysis to the journal′s papers published in the three previous years, divided by the number of the journal′s papers in these three years) and the relative database citation potential in the subject field covered by the journal (mean number of 1-3-year-old references per paper citing the journal and published in journals included in the considered database divided by that for the median journal in the database). Moed (2010) argued that the SNIP indicator, and specifically high values of this indicator, also provides information on the extent to which a considered journal covers emerging topics. Given the focus on recent citations and database coverage, the SNIP indicator is clearly associated with the radical novelty attribute of emergence. This indicator is, however, evaluated at the aggregate level of the journal and journal-by-journal. It is therefore less clear whether signals of radical novelty (i.e. relatively high values of SNIP) are associated with one or multiple emerging topics the considered journal may cover. In addition, the SNIP may not capture signals of radical novelty in those instances of journals that cover few emerging topics and therefore characterised by low values of SNIP.

All these techniques have various advantages and limitations. The qualitative analysis of news articles, editorials, review and perspective articles, for example, may be effective for contemporary analyses. However, the technical language used in these documents may be an important barrier to a non-expert′s efforts to independently assess radical novelty. The application of citation and co-word analyses is strongly dependent on time. Data need to be longitudinal in order to permit the tracing of cognitive dynamics and associated changes in the knowledge structure. Co-word analysis and bibliographic coupling are, however, less sensitive to time than direct citation and co-citation analyses and can be applied as documents become available (e.g. Breitzman and Thomas, 2015). Finally, overlay mapping provides a global perspective on emergence for the assessment of radical novelty, but interpretation of the resulting maps is mainly based on visual inspection.

Relatively fast growth: Emerging technologies show relatively fast growth rates compared to non-emerging technologies. The assessment of this attribute is particularly problematic for contemporary analyses. Growth is not yet observed in terms of publications and patents, for example, so scientometric indicators cannot be used. Early indications of growth may be revealed from the analysis of funding data, big data, and altmetrics.

In the case of retrospective analyses, ′relatively fast growth is perhaps the most frequently measured attribute of emergence in scientometrics. Most studies assume rapid growth as a sine qua non condition of emergence, and so a number of operationalisation approaches have been proposed. Indicators and trend analyses based on the yearly or cumulative count of documents — publications, patents or news articles, according to the nature of the examined technology and the availability of data — over a given observation period are widely used. Documents are generally identified over time by using expert-defined keywords appearing in the publication titles and abstracts (e.g. Porter and Detampel, 1995) or by exploiting more institutionalised vocabularies such as the MeSH classification in the case of publication counts in the biomedical domain (e.g. Guo et al., 2011). With a focus on patent data, de Rassenfosse et al. (2013) proposed counting the priority patent applications filed by a country′s inventor, regardless of the patent office in which the application is filed, as an indicator to identify fast growth and therefore potential emerging technologies. However, yearly publication or patent counts are always dynamic, so the problem becomes one of setting a criterion by which to distinguish the signal from the noise, that is differentiating emerging technology from other increasing trends.

Some theoretical foundations are needed to do this. Rapid growth is also detected by fitting the document count to a function (e.g. forms of logistic function such as Fisher-Pry curves). Bengisu (2003), for example, regressed the number of publications over publication year and defined emerging technologies as those technologies showing a positive slope and a decrease of less than 10% or stability (no increase) in the last period compared to the previous one, or no continuous decline in the last three periods of observation. Ho et al. (2014) instead fitted the cumulative number of publications to a logistic curve, whereas Abercrombie et al. (2012) extended the count of publications to patents, web news, and commercial applications. Data were then normalised and fitted to a polynomial function for comparison — a similar approach is employed by J¨arvenp¨a¨a et al. (2011) and Jun et al. (2014).

The number of documents is also used to detect ′bursts of activity′, i.e. the appearance of a topic in a document stream. This relies on the approach of Kleinberg (2002), who modelled the number of publications and e-mails containing a given set of keywords as an infinite-state automaton, i.e. a self-operating virtual machine that may assume a non-finite number of states and where the transition from one state to another is regulated by a ′transition function (similarly to Markov models). The frequency of state transitions with certain features identifies bursts of activity, which are used as a proxy for fast growth. The burst detection approach is combined with co-citation analysis by Chen (2006) to build a bipartite network of research-fronts linked with intellectual base articles. This network is then analysed in order to identify emerging trends.

Schiebel et al. (2010) and Roche et al. (2010) proposed instead an approach to emergence that is based on a diffusion model (and diachronic cluster analysis to identify topics) that combines a modified *tf-idf* with the Gini coefficient to identify three stages: ”unusual

terms", "established terms", and "cross section terms". Unusual terms are those that are rare in publications since they describe a research discovery at a very early stage. When research intensifies, terms first become more established in the original domain and subsequently they may diffuse into other domains, thus becoming cross section terms. Terms that change their classification (i.e. that show pathways) from unusual to cross section terms from one period to another are characterised by rapid diffusion and therefore relatively fast growth. This approach, however, is highly dependent on the thresholds of the *tf-idf* and Gini coefficient selected to classify terms as well as on the duration of the periods used to trace changes in the classification of terms.

Citation and co-word analyses can also be used to identify the relatively rapid growth of a potential emerging technology. Longitudinal analysis of the size of the clusters of documents or words obtained with the application of these techniques can detect knowledge areas that show rapid growth. For example, Ohniwa et al. (2010) used co-word analysis to cluster MeSH terms. For each MeSH term an increment rate was calculated in year t as the number of times the term occurred at time t+ 1 and t+ 2 out of the number of times the term occurred at t−1, t,t+ 1, and t+ 2. Fast growing topics are those in the top 5% of the increment rate in a given year.

Gl¨anzel and Thijs (2012) combined bibliographic coupling, co-word analysis, and a direct citation model. First, documents are clustered in time slices according to their cosine similarity resulting from bibliographic coupling and textual similarity. The core clusters identified through this process are next linked across different time slices via direct citations. Emergence is then detected by identifying clusters with exceptional growth — the study also considers emerging clusters to be those that are completely new with roots in other clusters or existing clusters exhibiting a topic shift, but this clearly refers to the radical novelty attribute of emergence.

Overlay mapping techniques can visually reveal knowledge areas characterised by a rapid increase in the number of documents (publications or patents) in the ′global maps of science or technology and which therefore, in comparison with other areas, may be growing at a faster pace. (Overlay mapping can also reveal diffusion across disciplines and technological areas.)

Other studies instead operationalised relatively fast growth by examining the growing number of authors involved in an emerging field over time (e.g. Bettencourt et al., 2008; Guo et al., 2011). For example, (Bettencourt et al., 2008) found that the growth of the population of authors in a given field tends to be relatively well described with epidemic models that consider novel ideas as spreading by ′infecting authors.

Coherence: Coherence and its persistence over time distinguish technologies that have acquired a certain identity and momentum from those still in a state of flux and therefore not yet emerging. Coherence in contemporary technologies may be detected by examining the scientific discourse around a given emerging technology. Initially, a variety of terms may be in use and reduction in the number of terms may signal increasing coherence. Abbreviations or acronyms take time to appear and, when they do, signal persistence; they also indicate shared interpretations and thus coherence (Reardon, 2014). Additional signals of coherence may come from the creation of conference sessions, tracks, dedicated conferences and subsequently from journal special issues and new specialist journals (Leydesdorff et al., 1994). New categories in established classification systems may also be created (Cozzens et al., 2010).

In retrospective analyses, entropy measures can be used (Watts and Porter, 2003) as well as clustering and factor analysis of citation and text networks. The coherence of clusters of documents or terms can be assessed in comparison to the overall network by applying, for example, local network density measures as well as by examining cluster persistence over time. Furukawa et al. (2015) propose using year-to-year coherence of conference sessions to indicate emergence. They applied co-word analysis to generate ′chronological networks of conference sessions (nodes) linked by their (cosine) similarity as based on the keywords included in the sessions papers — keywords were selected using the *tf-idf* indicator. Within these networks, emerging topics are defined as sessions where previous conferences sessions converge according to similarity.

In a similar vein, Yoon et al. (2011) developed a NLP algorithm capable of identifying properties and functions in the sentences of patent abstracts.12 The method generates an ′invention property-function network (IPFN). Nodes in this network represent properties and functions. A property is what a system is or has and is expressed by using ′adjectives+nouns′, whereas a function is what a system does and is expressed by using ′verbs+nouns′. Links between nodes are defined by the co-occurrence of properties and functions in patents. Emerging properties and functions are those clustered in small and highly dense sub-networks — i.e. de facto showing a certain degree of coherence.

The approaches discussed above examine cognitive dynamics. However, coherence can also be assessed on the basis of changes in the social structure. In this regard, Bettencourt et al. (2009) examined the evolution of co-authorship networks at the level of the scientist to identify network patterns associated with the emergence of new scientific fields. Increasing average number of edges per nodes (densification), stable or decreasing average path length between two nodes (diameter), and increasing fractional count of edges in the largest component of the considered network were suggested as signals of emergence and specifically of the topical transition of a field. These indicators clearly refer to increasing connectedness of the co-authorship network, identifying emerging communities as an indicator of emerging technology.

Prominent impact : Emerging technologies exert a prominent impact on specific domains or more broadly on the socio-economic system by changing the composition of actors, institutions, patterns of interactions among those, and the associated knowledge production processes. Scientometric methods cannot identify contemporary prominent impact due to a lack of data and the difficulty in delineating the technology in its very early stages (e.g. keywords may still be used by groups of actors with different meanings and in different contexts). Mixed qualitative-quantitative approaches used by Science and Technology Studies (STS) scholars on the role of expectations in driving technological change are of a particular relevance.13 The main argument of the sociology of expectations is that ”novel technologies and fundamental changes in scientific principle do not substantively pre-exist themselves, except and only in terms of the imaginings, expectations and visions that have shaped their potential” (Borup et al., 2006, p. 285). These expectations are ”real-time representations of future technological situations and capabilities [...] wishful enactments of a desired future” (Borup et al., 2006, p. 285) and they play a generative role by stimulating and steering as well as coordinating actions. Evidence of this has been found in a number of emerging fields such as gene therapy, pharmacogenomics, and nanotechnology (e.g. Hedgecoe and Martin, 2003; Martin, 1999; Selin, 2007). Expectations of the performance of novel technologies or, more generally, the ability of novel technologies to address societal problems are both important.

News articles, editorials, review and perspective articles in professional and academic journals, vision reports and technological roadmaps have all been used to identify statements representing multiple and potentially competing expectations surrounding a technology. STS work has also illuminated the central role played by hype in technology emergence. Actors who understand the constitutive role of expectations have an incentive to raise expectations in order to motivate the funding and activity needed to realise their preferred technological future. Hype, or over-claimed expectation, is often the result. This over-claiming can touch most attributes of emergence and especially prominent impact. For example, press releases prior to the launch of the Segway claimed it would ′change walking′. Similarly, in the case of coherence, for the government to fund nanotechnology research, they must ′believe nanotechnology is a ′thing′, as opposed to a name applied by some to a rather miscellaneous selection of materials science research activities. Therefore, proponents have an incentive to claim coherence where others might disagree.

These studies have been retrospective, but their data sources are contemporaneous with technology emergence so the method could be extended to contemporary analyses. Moreover, mapping of expectations can be combined with scientometrics when suitable data become available. Gustafsson et al. (2015), for example, used technological co-classification to identify clusters of patents, the full-text of which is subsequently analysed qualitatively to detect guiding images or leitbild, which are generalisations shared by several actors which guide actors towards similar objectives. Guiding images are used to explain the dynamics of expectations.

Retrospective analyses can rely more extensively on scientometrics, although this has not been done very often. Scientometricians have mostly focused on the detection and analysis of growth and novelty, whereas impact seems to be taken for granted. Nonetheless, scientometrics can greatly contribute to evaluating the impact of a potentially emerging technology. A number of techniques can be used to produce intelligence on the emergence process. These include the analysis of highly-cited documents, of authorship data to generate intelligence about the actors drawn into knowledge creation processes over time (e.g. private vs. public organisations and incumbents vs. newcomers), and of changes in the collaboration structure as mapped with co-authorship data (e.g. Hicks et al., 1986; Melin and Persson, 1996). Impact on knowledge production processes can instead be assessed by examining the dynamics of cognitive networks obtained from the study of the citations or the co-occurrence of terms across a particular set of documents.

Uncertainty and ambiguity: Emerging technologies are characterised by uncertainty in their possible outcomes and uses, which may be unintended and undesirable, as well as by ambiguity in the meanings different social groups associate with the given technology (Mitchel, 2007; Stirling, 2007). For analyses of contemporary emerging technologies, news articles, editorials, review and perspective articles on professional and academic journals can be examined to qualitatively assess the degree of uncertainty and ambiguity associated with an emerging technology as well as to identify possible multiple visions of the future associated with the technology. As for the evaluation of how prominent the impact of an emerging technology will be, an STS approach to the mapping of expectations can be used for the assessment of uncertainty and ambiguity.

For retrospective analyses, the evaluation of uncertainty and ambiguity remains largely unexplored in scientometric studies, however. The few attempts made along these lines tend to overlap with those already discussed for the evaluation of the coherence attribute,

since the main focus has been on the measurement of the reduction of uncertainty in scientific communication rather than on uncertainty and ambiguity associated with the potential impact or uses of emerging technologies. For example, the creation of a novel category (such as a new subject category in the classification of ISI WoS), in which subsequent journals associated with the emerging technology under examination may fall, is conceived as an indicator of increasing redundancy in the communication process — as new journals are established and achieve a critical mass to justify the creation of a new category, the redundancy of the communication process associated with the considered emerging technology has also increased. Increasing redundancy, in turn, may indicate diminishing uncertainty. In a similar vein, Lucio-Arias and Leydesdorff (2009) considered words in publication titles (which are selected by authors to position knowledge claims at a given time), cited references (which enable authors to position knowledge claims in the existing socio-cognitive domain), and time as key dimensions describing the scientific discourse at the research front of a specialty. The mutual information exchanged between these dimensions (measured in terms of Shannon entropy) is suggested as an indicator of uncertainty reduction.

Characteristics of Emerging Technology: The following sections describe the characteristics of ETs, which are also summarized in Table 1.

Uncertainty is high: Srinivasan (2008) pointed out that the only certainty with ETs is the high degree of uncertainty associated with them. The returned value/return on investment from an ET and the penetration rate at the early stage of the ET's lifecycle are unclear. ET transforms businesses and industries and sometimes destroys others. ET leads to radical change, and some firms prefer to wait for other leader firms to take the risk. Uncertainty is a core feature of ET. This is due to the nature of ET, whose future is unknown or unpredictable; what the ET holds for the future is unclear (Stahl, 2011). The uncertainty associated with a new technology takes several forms, such as uncertainty over prices or lack of knowledge about costs (Rosenberg, 1996). Meyer (2008) pointed out that technological uncertainty is represented by a lack of common knowledge and agreement about what production technology will be relevant in the future.

Furthermore, the lack of certainty and limited knowledge about technology standards and specifications, business models, and social implications make it impossible to describe the existing state or future outcome of ETs (Stanoevska-Slabeva, 2003). The uncertainty of future applications due to the lack of clearly defined business models in the early stages of technology lifecycles has led to skepticism (Schnicke, 2002). For example, Wang and Cheong (2005) stated that since mobile commerce was still in its infancy in 2005, there would be a lot of uncertainty about its future. This uncertainty caused the emerging mobile commerce market to be complicated. Akesson (2007) also notes that one of these uncertainties is related to the relative novelty of technology (i.e., m-commerce). This makes it very difficult to measure how people act in response to new services (Akesson, 2007). Thus, uncertainty here is related to different variables whose values are unknown, unpredictable, or unstable such as cost, penetration rate, technology standards and specification, and user acceptance and reactions.

It is clear that one source of uncertainty is a lack of standards and specifications for an ET. For example, NFC is considered an ET (Özdenizci et al., 2010). NFC is a wireless communication technology that enables the transfer of data over distances of up to 10 centimeters. This technology is used for mobile payments in the retail industry. NFC specifications are set by stockholders and players, which include MasterCard, Microsoft, Nokia, Samsung Electronics, Sony, Visa, Sony Ericsson Mobile Communications AB,

Research In Motion, and others (NFC Forum, 2012). The NFC Forum was formed in 2004 to advance the use of NFC technology by developing specifications, ensuring interoperability among devices and services, and educating the market about NFC technology. However, regarding specifications and standards, the NFC Forum website mentions that:

Work on more specifications is well underway. As a not-for-profit organization with many members contributing different input and views, it takes time for the NFC Forum to reach agreement and progress toward our goals. Other specifications in progress include Simple NDEF Exchange Protocol (SNEP), the NFC Controller Interface (NCI), and the RF Analogue Protocol. (http://www.nfc-research.at/)

Consequently, some specifications and standards were created in 2011-2012 to ensure that mobile-enabled NFC meets global interoperability, with more in progress. The lack of uniform standards has resulted in a lack of mobile-enabled NFC products, leading to a low penetration rate. However, this uncertainty gradually vanishes with time. If one refers back to 2004, much progress has been made. The timing factor is important. Since most ETs begin as a conceptual idea, some people or organizations wait until an ET matures and has specifications and standards. They may also wait until it is provided by many manufacturers so its price decreases due to strong competition. Before an ET is produced by many manufacturers, its standards and specifications need to mature. Gunasekaran and Harmantzis (2007) also pointed out that the standardization and interoperability between different vendor products have lowered Wi-Fi prices and facilitated its rapid penetration from a niche market into the worldwide mass market. The maturity of a technology is important because in the early stages of an ET's lifecycle, the initial adoption rate is very low because it is not stable. ET maturity leads to uniform standards for all developers, manufacturers, service providers, and end users. IT maturity has a positive impact on the adoption of IT investment evaluation approaches (Lin et al., 2007). This means that a decision to invest in a new ET depends on its level of maturity.

Network effects: The value and power of a network increases by increasing the number of people who use or are connected with that network. This law was formulated by Ethernet inventor Bob Metcalfe in the 1970s (Metcalfe, 1995). For example, the value of a fax machine is zero if no else has a fax machine. As the number of people (n) who own fax machines increases, the value of the fax machine to each user in the network increases. If only one user has adopted the ET, then its value in this context is meaningless. If two people adopt it, then the value is appreciated, and the value further increases if more do so, which increases adoption. For example, the number of users who have adopted Facebook is increasing due to its value, which increases by increasing the number of adopters. The number of users of an ET in a particular context begins low and then gradually increases. This is also correlated with time.

As long as time passes, the number of users will increase and the value of the ET will increase. Another example of ET is using NFC technology enabled in smartphones for mobile payments. The first trials for NFC technology started in 2006-2007 (http://www.nfc-research.at/). The first NFC-enabled mobile phone was developed by Nokia in 2006 (the Nokia 6131). Juniper Research forecasts that there will be a rapid adoption of NFC and that one in five users worldwide will have an NFC-enabled phone by 2014 (http://www.juniperresearch.com/). However, it is not worth having mobile-enabled NFC if no payment services using this technology are provided by merchants. If the majority of shops accept payment through NFC, the value of this technology will increase as will the number of adopters.

Unseen social and ethical implications: One feature that uniquely differentiates ET from other forms of technology is the fact that its social and ethical impact is not seen or known when the technology is eventually brought to the market or to a particular context. Usually, the added values and benefits are obvious. However, ethical concerns may arise depending on its application. If an ET is put into a new context, a new concern emerges. The impact of an ET changes as its application changes. For example, Radio Frequency Identification (RFID) was initially used for inventory management. When it was used for tracking criminals, it raised ethical concerns and debates about the tradeoff of peoples' privacy rights and countries' national security. Sandler (2009) indicated that some people have misconceptions about ethics and emerging technology. One of these is the belief that "it is too soon to tell what the social and ethical issues are" (Sandler, 2009, p. 6). This is due to the narrow focus on the technology's benefits and capabilities and the neglect of broader contextual factors.

In addition, Lucas (2011) pointed out that designers are not always aware that they are making ethical decisions when they develop or design new technology. Hence, these ethical problems are often discovered after the technology is placed in a particular context (e.g., place, domain, and application) and use. Therefore, when a new ET is created or used in a particular context, its emerging ethical concerns should be highlighted in the early stages of its lifecycle in order to use this technology in a way that does not harm societal and human values such as life, health, justice, freedom, happiness, privacy, and security. Although NFC technology is a relatively new emerging technology and is still not widely used, Halaweh (2012) addressed some of the social and ethical issues that could be raised, such as inequality among customers and privacy violations. He noted that this technology could increase inequality between people because it enables individuals who have Blackberry mobile phones, for example, to enjoy rapid payment services at checkout points, whereas others who do not have a smartphone will have to wait longer to pay by cash or with a credit card. An additional ethical concern is that banks will know more about customers, as they will use NFC-enabled mobile phones to pay for every purchase. Banks can collect data about their customers and analyze it to identify customers' purchase patterns and behaviors. In addition, technology might replace the traditional method of payment like carrying cash in one's pocket. Hence, it increases people's reliance on technology and the ubiquity of mobile phones. Although some of these concerns are not seen now, their impact might be discovered later when the technology becomes widely accepted and used by people and merchants. However, addressing such concerns in early stages could help in setting proactive actions to deal with them.

Costs: The term "emerging" is often taken to mean emerging from research and development (Vine, 2002). Cozzens et al. (2008) pointed out that because ETs are research-based, they are more likely to be sold at high prices as firms try to recover research and development costs. Cozzens et al. (2009) stated that the high costs increases the potential of ETs to increase inequalities in access among users. Although the point discussed here is related to costs, this also affirms the previous notion that ETs raise ethical and social concerns (i.e., inequality in accessing technology). On the other hand, Srinivasan (2008) pointed out that the costs during the early stages of the technology evolution process are low because the new technology is "buggy" with low performance and as the technology develops, its "bugginess" is eliminated. Thus, its performance and price ratio increase, and the potential benefits from the ET move from a narrow market to a larger mass market. New ET is always very expensive in the beginning because the initial production volumes are very low. These volumes are low because very few

manufacturers produce it; there is no certainty regarding adoption volumes. However, by the time the technology maturity increases, the number of manufacturers increase and the competition increases between them. Consequently, the cost drops in correlation with time. Hence, over time, the cost decreases and the spread increases. For example, the cost of an RFID tag started at $1.20 in 2005 but dropped to .05 cents by 2012. (http://moscatiello.net/) (http://www.rfidjournal.com/).

Another example is that the price of NFC-enabled smart-phones started at approximately $700, which is relatively high even in high-income countries. Users who would like to benefit from NFC technology have to purchase a smart-phone that has this technology. The NFC chip is not sold separately for users to add to their phones. Therefore, they have to exchange their old mobile phones for one that is NFC enabled; replacing old technology with ET is very high. The NFC microchip price might be cheap but the mobile phone that contains the chip is expensive; yet, this chip is available in a limited number of mobile phone brands. Therefore, its penetration and usage is delayed. If the chip is integrated into most inexpensive or affordable mobile phones, customers will accept it and merchants will offer mobile payments through this ET.

ETs are limited to particular countries: Technology-creating countries will always appear to be leaders who are starting revolutions, and technology-using countries will always appear to be attempting to catch up (Cozzens et al., 2009). New ETs have been developed in North America, Europe, and North Asia and then diffused to other parts of the world, either when a multi-national firm decides to place a production facility there or when the technology becomes available for purchase. For example, the first trials of NFC use started in the United States, Canada, United Kingdom, and Japan between 2006 and 2008 (Chidembo, 2009). Other countries, such as the UAE, introduced NFC technology for payment services in 2011-2012 (http://www.telecoms.com/). Of course, many countries are behind in terms of adoption and use of this technology. Industry-governmental coordination and support is important to the introduction and adoption of ET to a new context. Gunasekaran and Harmantzis (2007) pointed out that the penetration of wireless emerging technologies, such as WiMAX, requires national policymaker initiatives to develop suitable strategies that promote them, thereby maximizing the social and economic benefits to the country and its citizens. In their study of six innovations across 31 developed and developing countries, Talukdar et al. (2001) found that developing countries still demonstrated slower adoption rates than developed countries. Affluent countries compete for leadership in ET, and in the past, some less affluent countries found significant opportunities in the wide-open spaces of the technology emergence process (Cozzens, 2009). The availability of ET is an important condition for adoption. People in developing countries and less developed countries may hear about a new ET. However, because of economic conditions, they are unable to enjoy this

technology even though they wish to have it. If it is available to them, they will adopt it.

Characteristics	Description
ET uncertainty	The uncertainty associated with ET takes several forms with unknown and unpredictable values and outcomes, such as standards and specifications (maturity), business models, price, and adoption rate uncertainties. As time passes, the ET becomes more matured and diffused and the number of adopters increases while costs drop. In contrast, ethical and social concerns might increase as ET is used in new applications.
ET network effect	The value of an ET increases by increasing the number of ET users.
ET costs	The cost of owning the ET is high, and the cost of substituting traditional technology with the ET is high.
Unobvious ET impact	The social and ethical impacts associated with the use of ET are unseen, unknown, or unexpected before its adoption/use or at an early stage of the ET life cycle.
ET is limited to creator or inventor country (availability of ET)	ET is usually available for use in a particular context or in the country that creates or invents it.
ETs are not fully investigated and researched	Most of the materials on ET are white papers and technical reports produced by the manufacturers of the ET with little scientific/academic research.

Table 1. Characteristics of ET

ETs are not fully investigated and researched: In addition, research on ET is still not fully saturated; few articles are published. Most of the materials on ET are white papers and technical reports produced by manufacturers and stakeholders who benefit from this technology. This point was also asserted by Veletsianos (2010) and Thomas et al. (2009). This makes firms, governments, and decision makers unable to make decisions about ET adoption, applications, usage, and social implications because the main audience for these materials is professional industry personnel, which usually focus on the technical side of the ET. Well-established research about an ET's specifications, features and capabilities, limitations, and social implications will increase its adoption. For example, Thomas et al. (2009) pointed out that little scientific research has been published on NFC due to its recent emergence. Özdenizci et al. (2010) also noted that the literature review on NFC does not include many articles published in journals. Okazaki (2005) also pointed out that in 2005, the empirical explorations of m-commerce had experienced only modest growth because of the considerable uncertainties involved in mobile research. Therefore, well-established research on ET increases its maturity, knowledge about it, and thus its adoption.

Emerging Space Technologies:

Introduction: Space technologies have a long history with disruption. The last decade has seen widespread change— for example, governments and other public entities historically played a driving role in space research and services, yet tomorrow′s disruptive space technologies increasingly will be driven by commercial forces. And the future will bring additional disruption in the areas of human spaceflight, in-space manufacturing, and next-generation communications.

The combination of emerging technologies, new operating models, and other innovative concepts can accelerate the diffusion of space technologies across multiple economies and sectors: intelligent interfaces that integrate launch-range data into the National Airspace System; blockchain applications that validate remote sensing data; AI and machine learning applied to space science missions. These and other advances can help produce substantial value that extends beyond any one organization.

In the face of the changes ahead, it is not enough to simply plan for digital transformation and assume that success will follow. Organizations should look beyond the digital frontier—toward a future state in which transformation occurs across all mission portfolios and operating organizations. As industry and government leaders work to reshape their organizations, acquisition processes, and missions to take advantage of new digital capabilities, they will require fresh, focused, sector- relevant insights. Begin here, with this report that provides a timely perspective on Deloitte′s Technology Trends 2019: Beyond the digital frontier, focused specifically on the trends affecting the operators and users of space systems.

Macro technology forces at work: Nine technology forces (cloud, analytics, experience, blockchain, cognitive, digital reality, core modernization, cyber, and the business of technology) are the backbone of innovation past and present. Combining them compounds the effects of purposeful, transformational changeand can enhance mission resiliency, lower operational costs, or service more markets.

Getting started:

Learn from history: This is not the first time satellite constellations, low-cost space access, or remote sensing products have been tried. This time, they look to become the new normal.

Embrace technology at the core**:** New tools will affect the entire space mission, but only if acquisition and development embrace them faster.

Keep your eye on the horizon**:** New technologies, applied to current mission types, could have a profound effect on how we utilize space.

Trends in action: Organizations in the space industry are making more progress by integrating multiple pioneering new technologies than by piloting new tools one at a time. AI streamlines licensing and regulatory filing for satellite and launch operators. Blockchain enhances secure supply chains. Digital reality enhances mission assurance. Cloud provides a resilient backbone for space-based capabilities.

AI-fueled organizations: To harness AI′s full potential: find AI′s place in the mission, rethink talent, focus on human and machine interaction in environment, and deploy machine learning across core business processes and operations.

Getting started

***Decide what AI means to you*:** Applications can vary by mission, hardware, and operator need.

Strive to become an ″AI-fueled" organization: AI is not about replacing mission operators. It′s about improving efficiency for the entire organization.

Make AI part of acquisition decisions: Determine where AI could reduce procurement/operational costs—applicable in weather, remote sensing, or data-heavy missions.

***Look beyond your organization*:** ″AI-fueled" organizations require AI experts and best practices from multiple industries.

Trends in action: Organizations are already using AI to ingest weather and remote sensing data to provide real-time forecasts and insights. Use AI to turn mass-produced cube-sats into a highly customized platform for remote sensing and deep space exploration missions with self- healing and autonomous constellations.

No-Ops in a serverless world: Cloud providers have doggedly automated routine administrative tasks to improve their ″as a service" capabilities. Providers are looking to provide ground stations and other space applications services. Use the shift to create agile operations focused on higher- order (and higher-value) mission activities.

Getting started

Shift administration to an engineering: footing. Apply a systems engineering mindset to standardize, modernize, and synthesize infrastructure and systems.

***Have a strategy for your data and go cloud native*:** Pilot and pursue technologies that don′t involve managing physical servers and legacy hardware systems.

***Transform your processes*:** Make processes automatable and repeatable without human intervention.

Trends in action: Traditional ″as a service" providers are continuing to climb the stack, all the way through ground station antennas providing full turnkey services for customers. Organizations using new cloud computing models could increase utilization of space data. Address stovepipes between data stores and mission ops to enable ″pay by the drink" solutions.

Connectivity of tomorrow: Advanced networking offers a continuum of connectivity that can drive development of new products and services. From edge computing to 5G to low Earth orbit satellites, organizations are rethinking advanced connectivity options to design tomorrow′snetworks.

Getting started

***Plan for the upcoming explosion of bandwidth and spectrum congestion*:** A wirelessly connected world brings new demands and opportunities that will constrain the spectrum.

***Learn from history*:** This isn′t the first time bandwidth demand has exploded. Given commercial demand, can government users secure enough satcom bandwidth?

***Button down the status quo*:** Millions of new devices require new methods for interconnectivity—new ground stations, improved connected car antennas, or spectrum modulation, for example.

Trends in action: Mega-constellations, some more than 4,000 satellites, are being planned. Commercial satellite operators are building in-space edge routing and other networking platforms, mirroring terrestrial applications. Miniaturization trends extend to satellites across all orbits, providing new connectivity methods for areas not served by fiber or 5G. Advanced global connectivity can extend AI, image/facial recognition, and other tools into the field.

Intelligent interfaces: Working in concert, techniques and capabilities such as computer vision, conversational voice, auditory analytics, and advanced augmented reality and virtual reality can transform the ways we engage with machines, data, and each other.

Getting started

See beyond the long-established standards: Imagine new methods of delivering data to a user—real-time, high- fidelity weather data from multiple space and terrestrial sources to a pilot, for example.

***Rethink mission assurance and risk*:** Take advantage of new ways to continuously monitor or remotely assess via sensors and human interaction that could reduce time and cost.

Trends in action: With tablet-based AR, technicians can move from one system or mission to another efficiently, minimizing training needs. Specialists can use image recognition/speech capture to reduce time and cost of mission assurance. Technicians and/or astronauts can learn to repair machines virtually. New interfaces lay the groundwork for on-orbit servicing and other disruptive in-space supply chain concepts.

Beyond marketing: Experience reimagined: Today′s astute customers expect highly personalized, contextualized experiences. Users of space data crave dynamic, relatable engagements and insights. They want the cars in lots counted and the weather forecast, not to do the work themselves.

Getting started

*Look beyond traditional approaches:*Space data providers should rethink the ways customers interact with them.

Create connections: For down stream space applications, use new tools like AI to improve customer experience with data.

Go all-in on data: Collect and manage information from customers to understand use cases and improve their experience.

Trends in action:"Data middlemen"—who exploit, analyze, or disseminate data—represent areas ripe for disruption by macro technology trends. Combining AI with terrestrial and space-based weather sensors has already improved weather forecasting and accuracy; better user understanding has introduced this data into smartphones and mobile apps.

DevSecOps and the cyber imperative: Forward-thinking organizations are embedding security, privacy, policy, and controls into their engineering and IT delivery models. This

mindset changes the cyber design paradigm across the space, launch, and ground segments, treating it more like an engineering and risk management exercise.

Getting started

***Pick bold goals*:** Cyber resiliency built into the satellite. New modulation methods of protected tactical waveforms. Propel the design culture forward.

***Integrate security*:** Don′t test it in at the end—build it in throughout the system.

***Expand your security culture*:** Compliance is important, but focus on proactive risk management. Design and procure space systems with cyber in mind.

Trends in action: The US Air Force is currently using defensive cyber operations (DCO) to protect, detect, and respond to attacks on operational ground systems. Massive next generation satellite constellations provide resiliency, as well as targets. As such, constellations require attention to cyber security just like large-scale terrestrial networks. Secure the supply chain by leveraging trusted foundries, subsystem manufacturers and sensor suppliers.

Beyond the digital frontier: Mapping your future

Digital transformation has become a rallying cry for business and technology strategists. Look to the digital transformation pioneers to develop a systematic approach. Keeping up with what′s new prepares you to invent what′s next.

Getting started

Break down silos: Start with the end in mind; don′t let current designs or limitations drive decision making. Software-defined systems are redefining communications.

Procure prototypes and acquire capabilities: Others solutions should be your prototypes. Don′t be constrained by ″Not Invented Here" thinking.

Learn the landscape: Use multiple technology trends to create massive scalable and highly available functions to support the mission and operations.

Trends in action: Technologies such as AI and blockchain are helping industry leaders manage and secure tsunamis of data. The US Air Force′s use of the Space Enterprise Consortium (SpEC) provides a new, faster way to procure prototypes and capabilities with nontraditional partners. The creation of a portfolio architect for space acquisition and systems development represents a new approach to transformation.

Emerging Technologies and the Geospatial Landscape: This part provide perspectives and advice on how new technologies will impact the geospatial community. This section examines new and emerging technologies that will be of importance to Federal Government agencies using geospatial data, in the near- and medium-term future (~5 year horizon). The section identifies five overarching technology trends driving geospatial technologies, and then examines within this context the impacts on federal agencies in the core geospatial activity areas of data collection and generation, data analytics, infrastructure, access, and workforce.

Overarching Trends Driving Emerging Geospatial Technologies

We identify five overarching technology trends that are enabling, shaping and driving emerging geospatial technologies. These include:

- ***Real-time spatiotemporal data creation and interaction:*** Although real-time spatiotemporal data are now being generated by almost ubiquitously and their applications in research and commerce are widespread and rapidly accelerating, the ability to continuously create and interact in real time with this data is a recent phenomenon. This innovation is functioning as a core change agent in geography, cartography, GIScience, and many related geospatial fields, profoundly realigning traditional relationships and structures, expanding research horizons, and transforming the ways in which geographic data are now collected, mapped, modeled, and used, in geography and science and society more broadly. This real-time space–time interactive functionality remains today the underlying process generating the current explosion of fused spatiotemporal data, new geographic research initiatives, and myriad mobile geospatial applications in governments, businesses, and society.

- ***Miniaturization of technologies:*** Miniaturization to create small, and often inexpensive, devices, sensors, and wireless connectivity is driving an explosion of the Internet of Things (IoT). Miniaturized and lower cost sensors lead to an increase in what, when, where, and how much data is collected and, more importantly, the ability to tailor the sensor to the specific data collection need.

- ***Proliferation of new mobile geospatial sensor platforms:*** The rapid miniaturization of technologies has made it feasible to explore new modalities for sensor distribution, such as small satellites (smallsats) and unmanned aircraft systems (UAS, or ′drones′) that can be rapidly designed and deployed with orbits or flight paths tailored to the mission. These mobile geospatial sensor platforms greatly expand the capability of individuals, businesses, and governments to collect volumes of remotely sensed data for diverse and mission critical purposes, including disaster response, environmental monitoring, and public safety.

- ***Expanding wireless and web networks:*** The expansion of data collection methods, and the resulting volumes of real-time spatiotemporal data, demand improved methods for data transmission and distribution. Emerging new wireless and web networks are laying this groundwork.

- ***Advances in computing speed and capacity for geospatial research and applications:*** High performance computing networks (including CyberGIS) and cloud computing services (including CloudGIS) provide governments and others with conduits with which they can more easily access and contribute to repositories of geospatial data, tools, and services.

Emerging Technologies in the Federal Agency Geospatial Landscape

Below we examine impacts of the above overarching technology trends in five broad areas of the federal agency geospatial landscape. These categories are:

1. ***Data collection and generation*** – technologies that enable collecting or processing spatial and spatiotemporal data, introduce new data types, or have other significant

implications for data delivery and use. This includes impact on existing or de facto standards, real-time data generation and use, data confidentiality and privacy, and big datasets generated using these new technologies.

2. ***Data analytics*** – new technologies or methods to support analysis of big and small data, multi- dimensional, spatiotemporal, etc. These technologies include human-guided and autonomous, AI or machine learning type systems.

3. ***Infrastructure*** – infrastructure needed to support collection, processing, storage, sharing, and protection of data and systems.

4. ***Access (technology and data)*** – diffusion of technologies and data have been facilitated by improvements in access (e.g., changes in wireless systems and internet access). These changes impact who has access to the technologies and data, how we interact with them (e.g., types of device), and how we protect sensitive information.

5. ***Workforce*** – changes to the technology landscape require awareness of critical spatial thinking and technology skills needed for the next generation of spatial analysts, as well as consideration for how we broaden and diversify the geospatial workforce.

Technologies Impacting Federal Agency Geospatial Activities

Following is a discussion of specific emerging technologies of importance to Federal governmental agencies in the areas of data collection, data analytics, infrastructure, access, and the geospatial workforce.

1. ***Data Collection and Generation***

Real-time spatiotemporal data. The past few decades have witnessed an explosion of new geospatial data, including most significantly, fused spatiotemporal data. The changes in geospatial data collection wrought by real-time interactive GPS/GIS and its creation of mobile real-time space–time capabilities and applications are extensive. It is largely responsible for the highly detailed, specific, and updated GIS feature and attribute spatiotemporal data now available for governmental applications and GIScience research. It also has enabled the integration of GIS with mobile electronic sensors, such as environmental pollutant monitors, digital cameras, bathymetric instruments, noise monitors, biometric health sensors, and so forth, resulting in vast amounts of new continuously georeferenced and timecoded sensor data.

Real-time interactive GPS/GIS has spawned whole new industries, such as location-based services (LBS), and is a primary technology employed to create the navigational databases and street maps now used so widely by major Internet-map providers. It increasingly is a core component of the management of day-to-day real-time operations at most governmental agencies and large business organizations. It has also, in many ways, changed how wars are waged and military operations are carried out.

Broadening of participation. Another transformation enabled by real-time space–time interactive functionality is the enormous broadening of participation in mapping and geographic knowledge production to include the subject matter experts themselves (e.g., the botanist, the environmental scientist, the lineman, the archeologist, etc.), as well as community activists (participatory GIS), human rights organizations, and ordinary citizens through volunteered geographic information (VGI) and crowd- sourced geographies.

The proliferation of GPS-enabled mobile devices and sensors has resulted in new streams of real-time spatiotemporal data that is contributing to what is now termed geospatial ′big data. Moreover, technology miniaturization coupled with low-cost location-aware capabilities is driving the geospatial social media and big data revolution. Geospatial ′big data allows for the development and use of powerful predictive analytic and visualization capabilities that are increasingly important to government decision processes.

Small satellites (smallsat). Changes in satellite technologies are influencing the remote sensing industry in a significant ways as both space and airborne imaging sensors proliferate. The smallsat revolution is being driven by cost reductions associated with a wide variety of new technologies and ′new space business models. Sensor, launch, and insurance costs are all orders of magnitude lower than for the traditional, larger satellites.

More small satellites mean larger constellations and increased opportunity for meaningful monitoring. This creates new applications in many areas, including agriculture and forest management, environmental monitoring and impact assessment, natural disasters response and recovery, and national security concerns.

These trends generate new opportunities for mission specific sensors. If a specific spectral signature is required for a critical application, smallsats can be rapidly designed and deployed with orbits tailored to the mission. For instance, disaster response professionals often require specific spectral signatures to identify damage after a hurricanes, floods, and earthquakes. Sensors can also be ′tuned to find crops like poppies or specific oil related geology. Cost reductions associated with mission specific sensors will lead to increased commercial application such as counting cars at shopping centers or shipping containers at ports and harbors, as well as monitoring oil reserves for commodities trading. These opportunities will only grow as hyper-spectral sensors mature and offer thousands of spectral band combinations.

Unmanned aircraft systems (UAS). Additionally, the runway has been opened for drones with the 2016 release of FAA rules on the use of Unmanned Aircraft Systems. UAS proliferation and applications share many of the attributes of smallsats, but at an even lower cost. This increases the possibility of personal and small business use, putting a near real-time aerial monitoring capability in the hands of farmers, builders, inspectors, first responders, and the public. As with the opportunities afforded by smallsats, an expanded user community will lead to new sensors tailored to specific missions. Currently pre- programmed flight plans allow farmers to monitor crop moisture and nutrient levels multiple times per day, or to monitor new construction or open pit mines at the frequency needed for project managers and oversight bodies. The opportunities will be limited only by the imagination of the user communities.

2. Data Analytics

While data analytics is not an emerging technology, spatial data analytics are evolving in sophistication. A growing market of open source and commercial data analytics tools combined with increasing volumes of spatially referenced data makes the topic of interest to federal agencies.

The miniaturization of sensors has increased our capability to produce small, inexpensive devices to collect real-time data and produce geotagged messages or images, leading to new analytical challenges with large spatial datasets, including big data. Big data is

commonly defined as three Vs, which break down as: lots of data (volume), of different types (variety) that are collected/distributed at high speeds (velocity).

However, the power of big data has more to do with a fourth ′v′, its value. To get to the value of big data one must understand the ecosystem of technologies feeding and supporting big data. Advancement in web technologies has driven our connected world to the proliferation of data services, cloud software and hosting, platform integration, smart devices, and the Internet of Things (IoT). These advancements yield massive amounts of varied and continuous data – big data. While big data itself does not necessarily translate to knowledge, however, GIS and geospatial data provide the context, analytic capabilities, and understanding to the big data to better inform decisions.

Summarizing and visualizing aggregated spatial big data on a map allows users to immediately begin the analytic process of asking and answering questions about the data. For instance, where are disease outbreaks occurring based on sales at pharmacies? Or, where is insurance risk greatest given recently updated population shifts and storm patterns?

Big data, whether transactional business or government data or sensor data collected in the IoT ecosystem, requires context to understand and make it valuable. Geolocation and GIS feature and attribute data provides that context, by transforming the raw data into useful information and ultimately actionable intelligence. Advances in spatial data visualization and analytics are transforming the way governments and businesses operate, plan and deliver their services.

A recent Gartner, Inc. report forecasted 6.4 billion connected things will be in use worldwide in 2016, up 30 percent from 2015, and will reach 20.8 billion by 2020. Our hyperconnected world and evolving spatial data analytics enable better understanding of objects, environmental conditions, people and their interactions in real-time. These new capabilities raise technical challenges and policy questions related to privacy, human rights, data standards, confidentiality and security, and the management and dissemination of these data.

As the spatial-temporal data ecosystem expands, it will create opportunities for integrating data from billions of multipurpose devices through evolving communication technologies, which will support numerous GIS applications including geocoding, routing, geofencing, and spatial analysis, along with a full complement of geoenriched data. Geospatial analytics and GIS modeling will become more predictive and also potentially prescriptive during the next five years.

3. ***Infrastructure***

Since the Web became ubiquitous in early 2000′s, the core development of geospatial information science and technology has shifted from ″top-down authoritative" to also include ″bottom-up contributive" approaches. This shift takes advantages of cyber infrastructure and manifests itself in new geospatial methods of data acquisition, space-time analytics, spatial big data, geo-visualization, and interface design. Cyber infrastructure, on the broadest sense, delivers information computing and sharing facility over digital wired or wireless networks. From high performance computing networks (including CyberGIS) to cloud computing services (including CloudGIS), cyber infrastructure provides governments and others with access to conduits with which they can contribute to repositories of geospatial data, tools, and services. Over the years,

"bottom-up contributive approaches" have been developed and popularized, for example, volunteered geographic information (VGI), ambient geographic information from web crawling and crowd sourcing, location-based services, mobile geosensor networks, personalized navigation systems, social GIS coding, and geospatial UAS applications. New frontiers on mobile health (mHealth), Internet of Things, smart cities, and self driving cars pose new demands on geospatial cyber infrastructure for communication, storage, access, and analysis.

Self-driving cars, for example, will rely heavily on mobile creation of and access to real-time information among people, machines, and our environment. While the unit of data in transmission may be small, the boundless number of transmissions at one time with geo-enabled applications can crowd the internet bandwidth and stagnate progress. Cyber infrastructure, such as national broadband, is crucial to mobile access and the development of geospatial applications. New cyber infrastructure, such as programmable optical networks, holds promise for decreasing network delays, enhancing scalability, and offering rapid and efficient deployment of geospatial services. Federal policies also play a key role. The US DOT Federal Automated Vehicles Policy of 2016, for example, is helping to pave the way for the emerging geospatial infrastructure required for self-driving vehicles.

Data storage in the cyberGIS infrastructure is demanding but critical to deep learning of spatial patterns and associations. Cloud-based data storage and dissemination are creating more cost effective and flexible computing platforms. In 2012, the White House directed a cloud-first strategy to migrate 25% (or $20 billion) of federal IT spending to cloud-computing solutions. As government agencies and organizations expand commercial cloud storage, cyberGIS infrastructure needs should be considered.

In 2015, the Congressional Research Service identified challenges in federal implementation of cloud services. These include security requirements, organizational culture, acquisition processes, and funding for implementation. While technological advances have addressed some security requirements, policy and standard solutions will also be key to addressing these challenges.

New developments in fog computing, which facilitates the operation and management of computing, storage, and networking services between end devices and cloud computing data centers, will likely become more widespread. Because of neighborhood effects, spatial uncertainty and spatial autocorrelation, fog computing appears well suited as an infrastructure for local analyses that are essential to geospatial applications.

Threats to spatial cyber infrastructure. Spatial cyber infrastructure also is vulnerable to potential threats common to Internet, wireless network and power grid vulnerabilities. It is clear that this infrastructure for cyberGIS, cloudGIS, and GPS must be protected to ensure continued growth and use of the nation′s spatial infrastructure.

Key elements of spatial infrastructure such as GPS are exposed to disruption. On September 9, 2016, H.R. 5978 was reintroduced to create a ground-based back up to GPS, however, this was subject to the availability of funding. Past legislative efforts for this have not been funded. Geospatial services from navigation and routing to marketing and defense applications, are dependent on and intertwined with GPS in just about every aspect of the geospatial infrastructure.

Given needs for modernization of air traffic control, automated vehicles and autonomous drones, GPS protection should be addressed as a critical part of the nation′s geospatial

infrastructure. A cursory review of many federal agency plans reveals little mention of GPS or the National Spatial Data Infrastructure (NSDI). Federal agencies may wish to include the NSDI and GPS in their critical infrastructure protection policies.

4. ***Access***

A fundamental goal of democracy is to expand the engagement and active participation of citizens. Historically that has meant engaging in one′s community in an active, generally in-personway. However, the nature of technology today, with a plethora of devices and wider internet access, now provides a platform for immediate and global access to information and ways for people to engage and collaborate virtually. A majority of US citizens carry a web integrated, sensor laden, geo-located mobile computer in their pocket that makes this access ubiquitous and pervasive. Whether merely reading websites, getting directions, engaging with apps, or actively publishing information like reporting potholes, requesting help after a disaster, or collecting data as a citizen scientist, we have an unprecedented ability to interact with both our physical and digital worlds in coordination with one another, essentially integrating our work and our home life with real-time and historical data on just about anything.

A role of government historically has been to gather resources in order to build physical infrastructure such as roads, parks, and buildings, so that communities and commerce can grow and flourish. Increasingly, a new role for government is to provide a digital public infrastructure to support access to information, improve the efficiency of government operations, spur innovation and economic growth, and create a more informed citizenry and government. This digital ecosystem is more than just websites; new digital services are more responsive, spatially scalable, and mobile.

A noticeable shift in access and use of geospatial technologies is occurring. Innovation in geographic technologies originally occurred primarily in universities and within some governmental agencies. Increasingly, however, innovation in these fields now also includes the private sector, which has developed numerous commercial applications that depend on geospatial technologies. Consideration should be given to strategic alignment of public and private sector geospatial data requirements, funding, and public access. Opportunities for large public and private coordinated investments are particularly attractive in the emerging technologies addressed in this report, including earth observations such as aerial photography, satellite imaging, and high resolution lidar elevation data programs, which benefit broadly both public and commercial entities.

The democratization of geographic data can enhance transparency and foster productive dialogue. These capabilities present opportunities to increase the ability of governments to work smarter and simultaneously empower citizens to have an active and integrated role with their government. Data driven government and citizenship fosters collaborative decision making, issue advocacy, and community planning. The NSDI and the Geospatial Platform play a key role in enabling these trends.

Geospatial data and tools play a significant role in this new paradigm as the online mapping revolution is well underway, and the implications of this are far-reaching. Today consumer maps are common place on smartphones and the web. Map-based applications are among the most-used programs on smartphones and mobile devices. Online maps have helped millions of people to interact with their communities and governments. Quality, up-to-date geospatial data and tools are central to citizen access to governmental

programs and conversely, are an important means for federal agencies to interact and communicate with local communities and citizens.

5. ***Workforce***

Geospatial technologies are an integral part of many industries, including those that are not considered traditionally ′geospatial (e.g., emergency management, urban and regional planning, and oil, gas, and mining). While the emerging technologies discussed in this report by themselves present interesting challenges in the near-future of geospatial technology application, it is imperative that we also consider the impacts of these technological shifts with respect to the workforce that will be deploying

them. Perhaps the most significant general impact is the Bureau of Labor Statistics projected increase in demand for workers in traditional geospatial fields (e.g., increase of 29% for cartographers and photogrammetrists) and non-geospatial fields that rely on geospatial technologies (e.g., 11% increase for environmental scientists and specialists, 6% for urban and regional planners, etc.). While these numbers are indicative of the need for rapid growth in the workforce development pipeline, the technological changes reported in the report emphasize that this workforce also be trained with the critical geospatial thinking and technology skills required to adapt to emerging new technologies. As part of this workforce development challenge, we must also consider how to broaden and diversify this spatial workforce.

Taken as a whole, the technologies facilitating the collection, processing, storage, analysis, and display of spatial data require a distinct set of professional skills involving both spatial cognitive skills and understanding of geographic perspectives in order to appropriately structure the problems, solution pathways, and to interpret the results. This combination of expertise is not widespread, though it underpins many activities. In 2012, the NGAC presented a white paper focused on advancing geospatial workforce development. The white paper addressed STEM education opportunities, reliance on the Department of Labor Geospatial Technology Competency Model, and a focus on updates to the Standard Occupational Classification codes. We feel the recommendations presented in the 2012 white paper are still relevant and valid, and here extend the discussion to address concerns specific to development of a broad and diverse workforce to enhance our capabilities using emerging geospatial technologies.

A workforce prepared for addressing the challenges of emerging geospatial technologies requires a core set of transferrable critical spatial thinking skills that will be relevant to any geospatial technology (e.g., fundamental understanding of spatial relationships, map projection, and spatial resolution). While there is some K-12 emphasis on geospatial thinking and reasoning, it is largely absent from the US curriculum, and in higher education is often only emphasized in geo-technology programs. Many of the users of the data and products generated from emerging geo-technologies will not have formal geospatial technology training (e.g., GIS, remote sensing, & cartography coursework); in the long-term, increased emphasis on K-12 spatial and geospatial thinking development will help produce a broader potential workforce to engage in direct or indirect work with emerging geospatial technologies. While there are technical skills specific to emerging geospatial technologies, it is the underlying, transferrable higher order cognitive processes that provide a means to adapt and manipulate, interpret, and problem solve with geospatial data – regardless of specific technology. For instance, spatial inaccuracies introduced by application of incorrect map projections can, if not fully understood, distort visual or analytical interpretations.

While spatial thinking and reasoning skills form the basis for an adaptable geospatial workforce, there is additional need for a workforce trained to thrive in novel situations for data collection, processing, and analysis. For instance, we need training which focuses on the ability to collect and quality control volunteered geographic information (VGI), to develop geospatial tools and technologies that are accessible to non-geospatial experts, and to partner with citizen scientists.

Emphasis is also needed in ensuring that the geospatial workforce represents the growing US diversity, to facilitate approach of geospatial problems with a variety of perspectives. Diversity should be considered with a broad lens, to include ethnic, racial, gender, generational, and socioeconomic factors, but also diversity in training and background (disciplinary diversity with varying application backgrounds). Geospatial decision-making teams should reflect the nation′s growing multiculturalism, and should present a wide range of perspectives on national and international problems.

These broadened perspectives will improve the decision making process. There are also many ethical challenges in collecting, analyzing, and decision making with geospatial data. For instance, many emerging technologies have surveillance applications. The data they produce may be used – intentionally or unintentionally – to invade the privacy of private citizens. For more details, see the GIS Professional Ethics Project. We can minimize the impact of unconscious biases in decision making by ensuring we approach problem solving by building teams with diverse perspectives.

Emerging technologies that could impact geospatial industry: The UK Geospatial Commission has identified eight emerging technologies that could impact the geospatial industry and grow UK economy. This is part of a new report which came out on Tuesday, August 28, 2019. The eight technologies identified are:

- Cameras, Imaging and Sensing;
- Unmanned Vehicle Systems and Drones;
- Survey, Measurement and Scanning;
- Artificial Intelligence;
- Smart Sensors and Internet of Things;
- Immerse Technologies;
- Simulation; and
- Connectivity

The report is funded by the Geospatial Commission and published by PUBLIC, an organization that helps technology start-ups work better with the public sector. It analyzes commercial opportunities for use of geospatial data, considers the maturity of each technology in the UK, and provides numerous case studies and success stories.

Cameras, Imaging and Sensing: Definition: ″The platforms used to collect EO data and the equipment and instruments used to collect, store and process EO data.″ The ongoing digital revolution is unleashing an era of near-persistent observation. The range of imaging sensors are becoming as diverse as they are different with space, airborne, drone, vehicle, and ground-based imaging and sensing, as well as new sophisticated camera networks.This has opened up tremendous opportunities for the geospatial industry and the advances in technology in this area have been tremendous. First, we have seen the development and widespread adoption of new platforms for collecting EO data, including High Altitude Pseudo Satellites (HAPS), small satellites and drones, which led to resulted in greater coverage across satellite constellations, more accurate targeting, increased

capture options (time and place) for customers of EO data and the ability to undertake persistent observation and monitoring.

Second, there have been significant improvements in the resolution and accuracy of cameras and sensors, which has unlocked a number of new geospatial use cases.Other than the most obvious defense and security sectors, the greater accuracy that comes with the improved EO capabilities is crucial for sectors such as infrastructure, asset management and agriculture. The increase in the range of sensing capabilities available in

Multi- spectral and Oblique Imaging, Thermal IR and LiDAR will benefitindustries that require highly granular ground level data, such as agriculture and farming. Additionally, there will be opportunities in new sectors with the combination of aerial imagery with other map data and land use data, for instance deeper and more nuanced understanding of urban environments, enabling highly accurate 3D models.

At the ground-level, vehicle sensors are becoming increasingly common, with a number of different public and private sector organizations undertaking vehicle drive-by imaging and mapping surveys. These projects are being completed for a wide range of applications, including asset management, 3D city modelling, street canyon imaging and utility surveys. In addition, drive-by surveys are used as data sources for global on-line mapping, imaging and navigation platforms. Static and Backpack Imaging is another emerging trend in ground-based imaging. The emergence of backpack-mounted imaging systems and static camera options has been brought about by the requirement to image and texture 3D city models, provide imagery context for indoor spaces and support for floor plan mapping.

Unmanned Vehicle Systems and Drones: Definition: Unmanned Vehicle Systems are vehicles that are either controlled remotely or operate autonomously, by sensing their environment and navigating including without human intervention. Currently, there are three areas of major geospatial interest relating to drones. First, drones are being used as an aerial platform for EO and mapping projects. Second, they are being used as delivery systems for the delivery of lightweight packages, postal services and medicines. In recent times drones are being developed to carry and transport passengers within urban areas. Drones are also increasingly being used to support the monitoring and inspection of the condition of energy distribution assets and networks. In this, drones are leveraging Computer Vision to recognize images of infrastructural assets, using deep networks and convolutional neural networks to identify different types of faults and anomalies.

As drones become an integral part of urban environments, they are likely to be more frequently as part of the wider urban traffic management initiatives. Further, research is also underway to develop future Swarm Capabilities in command and control systems. In addition to policing and security, Drone Swarms will become increasingly applied to the monitoring of urban infrastructure. Over the next decade, we should expect to see the use of drones to extend from EO, mapping and monitoring into the domains of parcel and passenger delivery. For the geospatial community, the primary goal will be to provide first and last mile geospatial reference and navigation data to support these systems. This includes, as a minimum, systems such as geo-awareness, geofencing and GNSS- based locational requirements.

Survey, Measurement and Scanning: Definition: Survey, Measurement and 3D Scanning systems provide the foundation upon which the geospatial ecosystem is built. The report focuses on downstream GNSS chipsets, GIS data capture, 3D scanning hardware, software and value-add services. These technologies underpin above-ground,

underground and indoor positioning systems, in addition to being crucial for enabling numerous emerging technologies, such as Internet of Things, Autonomous Vehicles, Building Information Modelling, Virtual Reality, Artificial Reality and Mixed Reality. More accurate and precise positioning systems are central to operation of complex sensors systems at scale, such as IoT systems, where connected devices collect and communicate location intelligence by transmitting signals in real-time.

At the ground-level, there are a number of sensors that are becoming more widespread in surveying and measurement. Telemetry is the traditional process by which ground-based remote sensors transmit data to stationary data acquisition systems. Advances in ground sensors can enable Ubiquitous Positioning, where positioning can extend to indoor and more remote locations. This allows surveying and measurement to be conducted using multiple remote sensors, and is an important enabler of IoT systems and an ′always on concept of operation, which allows different sensors to communicate continuously.

LiDAR is a well-established geospatial technology that involves using pulses of light to capture and model a feature or an area environment in three dimensions. It can be applied across multiple sectors and requirements, including mapping an industrial site in granular detail, providing ground model data for flood modelling, and providing the spatial context for developing immersive environments. Indoor positioning is a particularly significant opportunity for the geospatial community since developments in this area has struggled to match the levels of innovation and widespread uptake seen in outdoor positioning. However, applications utilizing a mixture of bluetooth, WiFi and magnetic positioning can connect to smartphone without requiring any additional infrastructure.

Crowdsourcing or Volunteered Geographic Information (VGI) is another key emerging geospatial technology area. Other new techniques such as Analysis Ready Data (ARD), where EO data is processed into a useable form in real-time, and Robotic Process Automation (RPA) are being leveraged to support automated Feature Extraction for thematic and national mapping requirements.

Artificial Intelligence: Definition: Artificial Intelligence refers to systems or programs that can complete tasks that would normally require human intelligence, such as data analysis, visual perception, speech recognition or decision-making. AI will fundamentally change how analysis supports the day-to-day business operations, providing enhanced intelligence opportunities for entities a multitude of sectors. Machine Learning (ML) involves building statistical models based on sample data to make predictions or decisions without being explicitly programmed to perform the task. This has been effectively leveraged by geospatial companies to allow systems to derive insights and make decisions from structured and unstructured datasets with minimal human intervention. The EO industry in recent times has been able to apply change detection algorithms to automatically identify areas of change, including the identification of new areas of deforestation, urban development, or to support damage assessment mapping following disasters.

A number of service providers in the geospatial community have also moved towards supporting insurance intelligence requirements as ML becomes more effective at assigning risk- profiles to certain customer behaviors. Within the car insurance market, for example, patterns of driver behavior are now being processed and analyzed by ML systems with onboard devices, and linked to location to provide tailored analysis.

In Location Intelligence, GNSS and positioning technologies are being positively affected by AI, affecting industries such as logistics and navigation systems. For instance, through processing millions of GPS points in real time, systems will be able to forecast changing road and traffic conditions for truckers and haulers. LiDAR and Radar will also require enhanced automated analytical capabilities if future applications such as Connected and Autonomous Vehicles (CAV) are to become a reality. The E-CAVE (Enabling Connected and Autonomous Vehicle Environments) project, led by Ordnance Survey, aims to explore how CAVs can share positioning and safety information in real-time. Further, through this project, OS is also engaged in supporting and collaborating with CAV testing across four CAV test bed projects, announced in 2018.

Combining AI with other emerging technologies such as IoT will also bring about a number of new opportunities for the sector. The increasing number of sensors within Smartphones and other tracking devices require advanced analytics to draw meaning from the information that they transmit. For example, embedded health trackers and wearables increasingly assist health professionals in recognizing the signs of illness, aided by advanced diagnostic algorithms. Going forward, analytical systems will potentially be able to map population health metrics across entire communities, the adoption of advanced analytics will only improve such capabilities.

Smart Sensors and Internet of Things: Definition: Smart Sensors and the Internet of Things are the networks of physical objects that contain embedded technology to sense changes in their internal states or in the external environment, and communicate this information with other connected devices. To realize the true value of IoT, it is necessary to have greater integration between multiple sensors and smart devices, especially in the context of ′Smart Cities or other large connected ecosystems. Perhaps the most highly anticipated use of geospatial technologies and sensors is in the Smart City domain. Smart City applications rely on an integrated IoT network of devices across a set of different services and businesses.

Collation and consolidation of data from multiple geolocated and timestamped sensors and public sector datasets are becoming crucial to monitoring the security and resilience of assets in urban areas. Similarly, data-gathering motion sensors offer opportunities for continuous and real-time footfall analysis. Similarly, it is now becoming increasingly common to see mobile phone sensor data being used to analyze transport activity. There are a number of emerging companies using Crowdsourced mobile data to provide transport insights to cities and local councils.

In agriculture and farming, IoT solutions using geospatial technologies are seeing significant results. The main aim of IoT in farming is to monitor important environmental factors such as water quality, soil condition, ambient temperature, moisture, irrigation, and fertilizer for improving crop production.

There is an opportunity for geospatial analysis used in sensors for monitoring and supporting the management of future smart energy grids. These grids are composed of connected devices and sensors (including smart meters and smart appliances) and are capable of detecting changes in local energy usage in real-time. The roll-out of the smart grid relies on highly accurate geospatial information to ensure that demand analysis is accurate and reliable.

Immersive Technologies: Definition: Immersive technologies emulate physical environments through the creation of a digital space allowing visualisation and interaction

with an environment. Within the geospatial community, these technologies are typically used to produce advanced geovisualisation environments and to allow presentation of geospatial data. Any level of geospatial detail can be presented within an immersive reality, from a skeleton geometry in 3D, through to an Intelligent Point Cloud which updates as a real-time digital representation of a building. Geospatial acquisition technologies, such as LiDAR, provide a greater level of detail and context in the immersive model. Some GIS technologies are also becoming integrated with immersive systems, and we are starting to see the early adoption of these solutions in certain niche sectors.

A significant amount of Virtual Reality and Augmented Reality innovation is taking place in the military domain. In particular, these technologies are being used to improve the training conditions for soldiers in their preparations for conflict. Using wearable mobile devices, AR can transport users into new geographic locations to bring about context-awareness remotely. This is now broadening out to a whole new set of services within the armed forces, with pilots underway to assess whether maintenance engineers can give their expertise from anywhere in the world. However, these are early trials and this technology will take a number of years to reach full maturity. While in its relative early stages today, more R&D and innovation work in the geospatial enablement of immersive technologies over the next five years, could just make this a highly important domain area for geospatial exploitation going forward.

Simulation : Definition: Simulation technologies allow a user to model various scenarios within a digital environment. This involves building digital representations, or ′Twins′, of a specified geographical area, and manipulating relevant variables to model likely effects. Today, maps are increasingly becoming digital representations of a specific time and place, with users able to interact with and manipulate the underlying data. Geospatial simulations are already being widely applied in specific thematic areas such as flooding simulation and road traffic movement. The most significant future opportunities relate to the integration of thematic models at a city-wide, or even national, level.

3D Modelling is now a commonplace service offered by geospatial companies, and is expected to grow as the emerging technologies in this area mature. With advances in AI and ML, multi-dimensional modelling and simulation will improve maintenance and decision-making processes for organizations. GIS technologies also offer a number of benefits for modelling facility management scenarios, including space management, visualization and planning. Facility Operating Systems, which manage large operations such as airports, industrial and power plants will be the main beneficiaries of such developments. Increasingly, Smart Cities will coordinate these systems with smart sensor capabilities which will model and simulate urban planning. Fields such as construction and development are also increasingly adopting continual sensor monitoring and reporting on assets.

The greatest opportunity, and also challenge for the sector, lies in scaling these thematic modelling efforts to undertake city-wide scenario simulations. In general, however, for these simulations to be effective, there is a need for greater access to public and private datasets across a city. Digital Twin and Simulation technologies are growing rapidly in the geospatial sector. These technologies have the potential to support multiple future.

Connectivity: Definition: Connectivity technologies refer to the communications infrastructure across which geospatial data is transferred and exchanged. This includes satellite communications, as well as fixed and mobile telecommunications networks. The

higher speed and lower latency offered by 5G will allow data to be transferred more efficiently, cost-effectively and securely. Further, the geospatial community and geospatial data also has a key role supporting the planning, roll out and operation of our communications infrastructure. In addition to the ongoing investments to achieve full-fiber networks, going forward, the single largest game-changer in geospatial connectivity is likely to be 5G. 5G technologies use existing and high-frequency spectrum, enabling rapid data transfer speeds, making it easier to download and upload on mobile devices.

In addition, there have been dramatic advances in the network capacity of satellites over the past decade. Going forward, small and miniaturized satellite constellations — such as those operated by OneWeb — will present new global network and communications opportunities. Two further important connectivity assets in the UK are the cross-governmental Public Service Network (PSN) and Emergency Services Network (ESN), which will support communications between front-line officers and bluelight services. These emerging high-capacity, fast, and low latency communications channels will enable geospatial data to be transferred at volume, at speed and securely.

Improved network capacity and data speeds will allow the expansion of the use real-time image and video streaming, including HD and Ultra‑HD Video. One clear use case for improving network capacity in public spaces is for persistent monitoring and surveillance using video and image streaming for specialized policing and security services. Better connectivity will also allow more geospatial players to leverage the scalability and computing power offered by Cloud computing. Improved connectivity to the cloud will allow data to be stored and processed in Cloud centres in real-time, allowing constant connection between field, office and Cloud. Improved local connectivity will also allow geospatial actors to develop new Edge Computing strategies. Edge Computing relies on local networks of micro data centers close to the sensor or scanner, and is particularly important for delivering lower-cost data processing and storage for IoT systems.

The reduced latency of 5G technology will be crucial to the future adoption of Autonomous Vehicles and drones. Since autonomous vehicles require extremely fast networks with no delay or lag to operate, this reduced latency will also better support the effective streaming of real-time imaging data on the move, as well as continuous sensor availability to support spatial analysis at scale in real time. Constant and secure connectivity will also be crucial for drones and other unmanned vehicles when performing missions covering large land areas, including surveying, mapping and the monitoring of energy grids.

Improvements in Satellite Communications are enabling high- volume geospatial data to be transmitted across these networks, which could previously only handle low volume audio data such as voice. To support the significant investments and operation of our communication infrastructure, telecommunications and utility companies require a wide range mapping, survey and geospatial analysis services. These not only represent significant future opportunities for the geospatial community, but they also demonstrate how the geospatial community can both benefit from and enable the development of key emerging technologies.

Other emerging Technologies: In addition to the above emerging technologies, the following technologies also impact the geospatial industry:

Cloud Computing: The evolution of cloud infrastructure has provided the advances in Big Data Analytics for geospatial technologies as GIS systems contain a wealth of

information from geographical locations. These advances provide geospatial data a flexible, on-demand computing platform to combine observation systems, parameter extracting algorithms, phenomena simulations, analytical visualization and decision support. This further facilitates with social impact and user feedback that are the significant elements of the geospatial sciences. Advanced computing networks such as CyberGIS and cloud computing services like cloud GIS are offering governments and others with conduits where they can more easily and quickly access and contribute to growing repositories of geospatial data, tools, and services.

Big Data: Big Data in this sector refers to datasets that exceeds the capacity of current systems. The traditional geospatial data that contains remotely sensed data was structured and analyzed in data analytics systems like GIS. However, with the emergence in faster and broader wireless and web networks, modern data with useful geospatial content like photos, social media chats, video, voice and messages now constitute almost 80 percent of the total data. In its unstructured form, it cannot be utilized in conventional analytic systems like GIS and the amount of data generated by these platforms far exceed the data storage capacity available.

Thus, Big Data here comes with improved innovation, sustainability which converts the sheer volume into billions in savings.

Open Source GIS Mapping Software Empowers Innovation: Open-source GIS mapping software gives users access to powerful tools for creating maps and adding elements such as text, images and video. Particularly in conjunction with initiatives such as OpenStreetMap or the Open Geospatial Data Project, these applications offer endless possibilities for collecting and visualizing spatial information and customizing maps. Users create projects to:

- Highlight the demographics of a region
- Trace the availability of natural resources over time
- Chart crop growth and capture any evidence of disease
- Demonstrate how changes in environmental conditions affect the preservation of a historical site

The flexibility to assemble maps for diverse purposes has a growing impact in daily life, influencing progress in smart city infrastructure. With extensive locational data, government agencies and private businesses can deliver services more efficiently and strategize sustainable development. Customized maps may be applied to augmented reality projects that provide workers with helpful details tied to a specific location.

Meanwhile, open-source mapping has a huge role in the burgeoning world of navigation systems and automated vehicles. When setting routes, these systems account for a widening range of factors, such as traffic conditions updated in real time and individual preferences. GIS is essential to improving performance in self-driving cars and guiding drivers to their destinations as quickly, comfortably and safely as possible.

Bringing together GIS and Drones: Organizations and consumers employ unmanned aerial vehicles (UAVs) for an ever-expanding list of applications, from entertainment to agriculture, often relying on navigation supported by GIS. For instance, experiments with making deliveries by drone have unlocked possibilities for getting food and other products to customers with unprecedented speed. Other companies are deploying the aircraft to collect information from IoT sensors that monitor industrial sites, hazardous

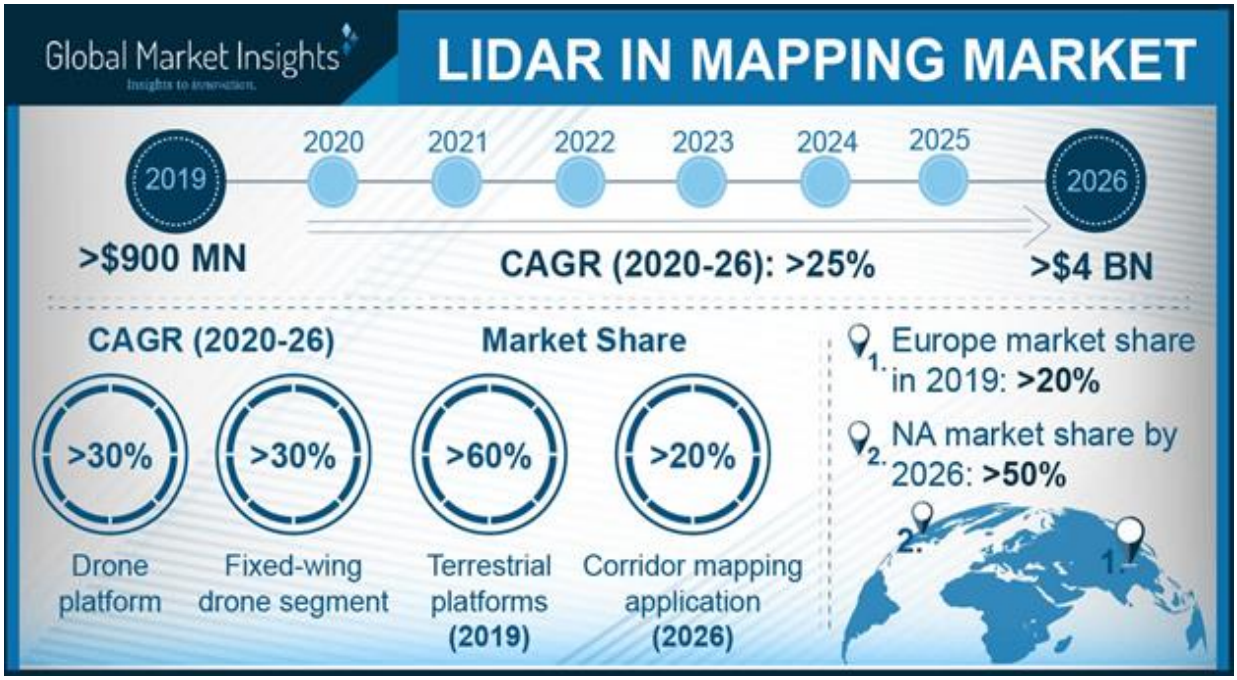
travel conditions, volatile weather patterns or the wellbeing of crops and send real-time updates.

Meanwhile, drones also improve the information that is available for mapping and manipulation with GIS tools. A great deal of spatial data comes from satellite imagery and readings taken by manned aircraft, but drones are a cost-effective means of gathering extensive details on a smaller scale. UAVs thus have a major role to play in making geographic information more readily available for open-source mapping and customizable to fit the priorities of businesses, governments, independent researchers and hobbyists.

Trends for Demand for LiDAR in Mapping Solutions worldwide: It was in 2018, that a breakthrough in LiDAR technology enabled the world to witness a prominent surge in the adoption of numerous systems and solutions integrated with LiDAR. As per news reports, a team of 18 researchers mapped over more than 61,000 structures in the Maya lowlands in 2018, which provides the scientists information to study the most extensive maps of the Mayan civilization till date. Reports claim that a discovery like this was only possible through airborne LiDAR, which offered a new growth prospect to the overall LiDAR in mapping market.

The progression in overall LiDAR in mapping market can be attributed to the rising demand for improved urban planning on the grounds of expanding urban population and emergence of smart cities concept worldwide. In line with this, a surge in demand for reduction of risks associated with natural disasters like floods, earthquakes, and volcanic eruptions, has also triggered the need for LiDAR in mapping solutions.

Even though the 21st century is witnessing a massive demand for such solutions, high cost of resources being used for single project operations would serve as a main obstacle in the market growth, negatively influencing the revenue generation. However, its increasing demand for modern surveying techniques across oil and gas fields and innovative transformations about cost association would offer a lucrative growth path to the overall LiDAR in mapping industry.



Global Market Insights, Inc., predicts that the worldwide LiDAR in mapping market will record a valuation of USD 4 billion by the end of 2026, in lieu of the below mentioned trends:

LiDAR mapping in oil and gas production and exploration industry: The deployment of LiDAR in mapping industry has been of immense importance to the oil and gas sector. The intervention of government bodies in order to identify new sources of energy and take subsequent steps further, would also potentially accentuate the market share in the years to follow.

Government authorities have been making extensive use of LiDAR in mapping technology to locate suitable locations to place pipelines for O&G industry. Let alone the government initiatives, private companies have also been standing at the forefront to make use of this technology for quick and safe mapping of distant oil and gas fields. Say for example, a Brazilian O&G inspection services provider- Terra Drone Brazil, in 2019, announced performing an extensive aerial LiDAR mapping for the country′s state owned energy firm- Petrobas with an intent to identify cracks, corrosion, and surface welding defects in ballast tanks and cargo.

Novel innovations in LiDAR in mapping business space : Elaborating further on the market strategies being undertaken by various industry majors in the field, it is pivotal to mention that these companies have been looking forward to introducing low cost LiDAR sensors to target the expanding mapping market around the globe. Citing an instance for the aforesaid, recently, a German automaker- Robert Bosch announced developing a LiDAR sensor that allows self-driving cars to have a 3-D view of the road. This innovation comes on the heels of company′s idea of offering low cost technology to its customers, which accelerates the development of self-driving automobiles.

Town planning- a new market domain for LiDAR in mapping solutions: Construction and surveying segment have emerged as a remunerative vertical for the global LiDAR in mapping market, recently, courtesy- the technology′s widespread use in town planning. With population gradually rising and urbanization expanding at a rapid pace, need for new constructions have been dramatically rising. This has indeed compelled the construction companies to make use of drones equipped with LiDAR technology for performing survey-grade topographic mapping. A fundamental use of this technology significantly reduces operational costs and human risks in difficult terrains.

Japan- a potential growth ground for LiDAR in mapping industry: With about 1500 earthquakes striking the nation almost every year, Japan has emerged as a profitable growth ground for LiDAR in mapping industry. Thanks to the elevating demand for improving disaster management systems across the country. Speaking of its rising prominence in the region, the Japanese government had in 2017, deployed LiDAR mapping systems to asses post disaster damages created by the Kumamoto earthquake that occurred in the country in 2016. The acquired data was used for creating strategies to effectively deliver and distribute relief resources during the occurrence of such emergencies. All in all, the above-mentioned trends are expected to open new growth opportunities for the adoption of LiDAR in mapping solutions worldwide, in turn propelling the global market progression over the forthcoming years.

MODULE-IV

LEGAL ISSUES OF GIS TECHNOLOGIES

MODULE-IV: LEGAL ISSUES OF GIS TECHNOLOGIES

Legal and Ethical Issues of Using Geospatial Technologies in Society:

Introduction : Geospatial technology, along with bio- and nano-technologies, has been recognized by the scientific community as one of the three leading technologies that will shape the development of science, technology, and society in the years to come. Generally speaking, geospatial technology is an amalgamation of several technologies, including (but not limited to) remote sensing (RS), geographic information systems (GIS), global positioning systems (GPS), location-based services (LBS), and related fields such as computer mapping, spatial modeling, and data visualization. Not very long ago, an editorial in the Wall Street Journal alerted its readers that "... tools of geographers are changing society today as much as the tools of physicists did at the time of the atomic bomb". Indeed, the atomic bomb could serve as an illuminating metaphor for the mixed, far-reaching, broad social impacts we are just beginning to appreciate for geospatial technologies. On the one hand, it has been demonstrated that geospatial technologies can be used to document cases of gross human rights abuses, find land mines, and identify concentrations of the poor and the hungry in dire need. On the other hand, recent years have witnessed a growing outcry by the general public on the increasing use of geospatial technologies for tracking people.

Indeed, the growing applications of geospatial technologies have contributed to a new geography of hope and fear, which concomitantly raised a series of legal and ethical issues. During the past five years, we have witnessed an increasing coverage by both popular media and scholarly articles on the issues brought by the breathtaking development of geospatial technologies and their expanding capabilities for surveillance purposes. Since its very early days, geospatial technology has been characterized as a major tool for surveillance, and today it has become an integral component of the surveillance infrastructure. Not surprisingly, concerns about unintended consequences have also grown with the increasing sophistication of these surveillance capabilities. The social implications of GIS have always been one of the major research areas in geographic information science. Scholars in many fields have contributed to our understanding of GIS from legal and ethical perspectives, but the scholarly work on this topic has been scattered throughout a large interdisciplinary literature. The primary goal of this chapter is to present a synthesis of the literature on the legal and ethical issues of using geospatial technologies in society. In doing so, I aim to bring the legal and ethical dimensions of geospatial technologies to a broader audience and help open more dialogues and discussions among the stakeholders in this area. To achieve this goal, we shall first review the key elements of the new geospatial technologies that have enhanced our surveillance capabilities, followed by a synopsis of the legal and ethical problems these technologies have brought to society in the third section. The fourth section discusses some possible remedies for these problems, and the last section contains a summary and conclusions.

The Changing Technological Landscape for Positioning, Tracking, and Mapping: From Surveillance to Sousveillance: Although concerns over legal and ethical issues of geospatial technologies were voiced throughout the 1990s, these discussions were confined to the scholarly community and did not gain much public attention. This was primarily due to two reasons. First, earlier applications of geospatial technologies focused disproportionately on environment and resource applications at a crude spatial resolution (10 m by 10 m or coarser). Those dealing with socioeconomic applications were conducted mostly at the aggregate level, not focusing on individuals explicitly. Second,

high-resolution satellite remote sensing or aerial imageries (sub-meter resolution) were tightly controlled by government (mostly classified), and GPS, although in use from 1972, was not declassified for civilian applications or commercialization until 1983.

The developments of geospatial technologies during the past 15 years have dramatically changed the technological landscape. Recent advances in surveillance capabilities of geospatial technologies have rendered science fiction movies, such as Enemy of the State (produced in 1998), more like a documentary in the early days of the twenty-first century. The new technological breakthroughs have not only equipped Big Brother with the ability to conduct extensive surveillance on citizens, but have also empowered individual citizens to conduct surveillance among themselves or inverse surveillance on the watcher. Furthermore, under the new paradigm of citizens as sensors, individuals, and informal groups of individuals popularly known as smart mobs, can record, describe, and disseminate information on activities at either the individual or collective level from the perspective of the participants – a new form surveillance called sousveillance. Several key components of the geospatial technologies have contributed to the transition from surveillance to sousveillance.

Throughout human history, a variety of different location technologies, ranging from mechanical, acoustic, optical, radio, and electromagnetic, have been developed. Generally speaking, geotracking – obtaining the locational coordinates of the target being tracked – has mostly relied on three primary techniques for determining location: (1) triangulation, which can be done via either lateration (using multiple distance measurements between known points) or angulation (using measured angles or bearings relative to points with known separation); (2) proximity, which measures nearness to a known set of points; and (3) scene analysis, which examines a view from a particular vantage point. Different geotracking technologies use different combinations of these three techniques.

These different technologies have different coverage, spatial-temporal resolution, and accuracy, and have increasingly been embedded into a variety of consumer products such as car navigation systems, smart cellular phones, printers, underwear cosmetics, and so on (Table. 1). Custom-designed tracking devices have also been available in the market, such as Digital Angel, Wherify child locator and various other types of WhereWare (Pfeiffer, 2003). Among the many technological breakthroughs during the past 15 years, the following are particularly relevant when we discuss the legal and ethical implications of geospatial technologies:

Global Navigation Satellite Systems and High-resolution Remote Sensing: Among these different positioning technologies, perhaps the most significant one is the global navigation satellite system (GNSS), which was instrumental in promoting the development of location-based industry. As of 2009, the US NAVSTAR GPS is the only fully operational GNSS. However, the global dominance of positioning systems by the USA is eroding with rapid development of GNSS by the EU, Russia, China, Japan, France, and India. The European Union's Galileo positioning system is a GNSS in the initial deployment phase, scheduled to be operational in 2013. The Russian GLONASS is a GNSS in the process of being restored to full operation. China has indicated it may expand its regional Beidou navigation system into a global system.

The current Beidou-1 system (made up of four satellites) is experimental and has limited coverage and application. However, China has planned to develop a truly global satellite navigation system consisting of 35 satellites (known as Compass or Beidou-2). The Quasi-Zenith Satellite System (QZSS) is a proposed three-satellite regional time transfer

system and enhancement for GPS covering Japan. The first satellite is scheduled to be launched in 2010. Doppler Orbitography and Radio-positioning Integrated by Satellite (DORIS) is a French precision navigation system. Indian Regional Navigational Satellite System (IRNSS) is intended to be completed and operational by 2012. Obviously, more and more countries have recognized the growing importance of GNSS to their military operations as well as various civilian applications, which explains their growing investment in the global navigation infrastructure to develop their own independent systems.

Table-1: Location/Positioning Technologies

Technology	Coverage	Accuracy	Updates	Location Data
GPS	Earth	0.01m-100m	<1s	x, y, and z coordinates
Mobile phone (tower triangulation)	Populated areas	120m-30km	4.6ms-2hrs	x, y coordinates
CCTV	City centers	1m	1/30s	Camera location
RFID	Near readers	1m	Sporadic	Distance to reader
Credit card	Payment Kiosk	1m	Sporadic	Kiosk location

Advances in remote-sensing technologies have made high resolution (sub-meter) commercially available satellite from GeoEye and DigitalGlobe (see http://www.vterrain.org/Imagery/commercial.html for a more complete list of vendors). The corporate sector is increasingly interested in collecting information at the local and individual level. GoogleTM and Microsoft® are investing in Street View (http://www.everyscape.com/). Satellite navigation systems and high-resolution remote sensing are instrumental in contributing to what Regan (2004) called the creeping legibility of both people and places.

Radio-frequency Identification and Biometric Systems: Radio-frequency identification (RFID) technology relies on storing and remotely retrieving data using radio waves. An RFID tag can be attached to or embedded in a product, animal, or person for identification or tracking. An RFID chip typically is composed of a tiny antenna attached to a tiny ID chip, and it can be passive (without an internal power source) or active (with a built-in power source). As GPS signals are usually too weak to be used for tracking purposes inside a building, the development of RFID technology, especially once it is fully integrated with GIS, may potentially track and map everything on surface of the earth. EPCglobal, a system of tags to create globally unique serial numbers for all products using RFID technology, may be a concrete step forward toward stitching together a new electronic skin for the Earth.

Since each individual is identifiable spatially and temporally via GPS and RFID, we are subject to the linkage of our positioning information to other types of biometrics such as finger prints, iris/retina scans, face recognition scans, or thermal maps of the body, as well as to detailed genetic information at the individual level (http://www.23andme.com). GPS and RFID especially in the form of sub-dermal implantation, along with biometric

and genetic information, have brought surveillance to a new level of unprecedented detail ranging from genetic all the way to global levels. One particular interesting recent trend is the integration of GPS with RFID. The two complementary systems could potentially close the location positioning gaps for the entities we aim to track and map.

People-based GIS, Participatory Sensing, and the Development of Sensor Webs: One of the most significant advances is the development of people-based GIS. Until the mid 1990s the development of GIS had been driven by a place-based paradigm, in which environmental and socioeconomic data are aggregated to spatial units of various sizes (e.g., census tracts, traffic analysis zones, or grids of varying sizes). We often rely on place-based, aggregated information to infer information about individuals. Advances in information and telecommunication technologies and related changes in peoples' activity patterns have increasingly made such inferences problematic. Inspired by Hägerstrand's time geography and activity theories, Miller (2007) proposed the concept of people-based GIS, which is capable of monitoring, tracking, analyzing, and visualizing people's activities in space and time. Many real-world applications such as transportation planning, emergency evacuation, and disease surveillance all demand people-based, rather than place-based GIS. The development of people-based GIS represents a major conceptual departure from place-based GIS. The increasing applications of people-based GIS are made possible because of a growing array of location-aware technologies.

People-based GIS is made possible partially by the location-aware technologies such as the smart cellular phones people carry with them. Detailed spatial and temporal information is recorded, thus making the spatial and temporal analysis of trajectories possible. Humans are becoming sensors for collecting data about other people and the environment. The so-called participatory sensing – individuals using cellular phones to collect data – has emerged in recent years with growing areas of applications (Burke et al., 2006). Participatory sensing is an integral part of the emerging sousveillance.

Ubiquitous Computing, Web 2.0, and Volunteered Geographic Information: The explosive growth of Web 2.0 technologies and the concomitant growth of user-generated content marked a new era for the development of geospatial technologies and their surveillance applications. Perhaps the most significant development for this new era is the dazzling growth of volunteered geographic information contributed by citizens using Web 2.0 technologies through the new paradigm of cloud computing. In addition to its contributions to a bottom-up process for the growth of spatial data infrastructure, VGI is also contributing rather significantly to the social transition from surveillance to sousveillance, as a large amount of VGI reflects extreme details about personal experiences voluntarily provided. Besides the explicitly geocoded data that citizens contributed to VGI sites such as openstreetmap.com or wikimapia.com, the past five years have also witnessed the rapid growth of geotagged, user-generated content on the web, ranging from twits, blogs, and photos, to YouTube™ videos and online social networking activities on Facebook™ or MySpace™ . Nowadays even Twitting is increasing geotagged and readers can tell where you are twitting from. The emerging new infrastructure for ubiquitous computing (ubicomp) has increasingly become context- or location-aware, which contributes to both surveillance and sousveillance capabilities unprecedented in human history.

Indisputably, ubicomp will embed more conventional GIS functions into various kinds of enhanced LBS. Location-aware computing, or more broadly ″context-aware" computing, will equip information infrastructure of all kinds with special capabilities to recognize and react to real-world contexts in which it operates. ″Context" encompasses a plethora of factors, including user identity, time, physical location, and environmental conditions (such as local weather, and so on). The two most critical aspects of context are location and identity. Context-aware computing systems respond to a user's location, either spontaneously (e.g., a friendly reminder of approaching a favorite restaurant, or warning of a nearby hazard) or when activated by the user's request (e.g., is this area prone to traffic jam or accidents?). With the continual growth of a variety of LBS, many GIS functions that were previously confined to desktop PCs may become embedded as part of ubicomp or ambient intelligence.

The development of ubicomp will also entail another round of explosive growth of data of many kinds with greater spatial and temporal resolution. Real-time data acquisition (RTDA) will become a reality in the age of ubicomp, which will make just-in-time mapping (JITM) a routine operation in the near future. For example, the development of smart ″dust sensors" – devices that combine microelectromechanical sensors with wireless communication, processing, and batteries into a package about 1 mm3 in size – could potentially revolutionize RTDA and JITM. Although currently still in their infancy, prototype smart sensors have demonstrated their capabilities to monitor environmental conditions that are hazardous to humans, determine the velocity and direction of passing vehicles in remote areas, or to be attached to humans, animals, or even insects to record where they travel. The data transmitted wirelessly in real time from these sensors increases not only the volume but also the complexity of available geospatial data. To store and analyze these colossal data sets obviously demands more storage space and computers more powerful than ever for data mining and research. So paradoxically, the age of ubicomp will also simultaneously create new demands for more powerful mainframe and personal computing as well. The theoretical foundations and functional capabilities of GIS in data acquisition, storage, analysis/modeling, and visualization need to be expanded to accommodate the new demands created by ubicomp.

Data Mining, Knowledge Discovery, and Geographic Profiling: The growing availability of massive amounts of geocoded information has contributed to rapid development of a variety of new data mining and knowledge-discovering techniques. These techniques are capable of conducting integrated analysis of heterogeneous data sets to detect meaningful structure and patterns. In addition to techniques for handling quantitative data, recent developments have also led toward breakthroughs in text mining and photo synthesis (http://photosynth.net).

The increasing availability of geocoded data, coupled with our improved capabilities in data mining and knowledge discovery, has resulted in new spatial practices called geographic profiling. Geographic profiling originally developed as a criminal investigative methodology that analyzes the locations of a connected series of crimes to determine the most probable area of offender residence. Geographic profiling helps police prioritize information in major crime investigations that often involve hundreds or thousands of suspects and tips. Most recently, techniques of geographic profiling were used to zero in the possible location for Osama Bin Laden. Although typically used in criminal investigation, such as in cases of serial murder, rape, arson, bombing, robbery, and other crimes, geographic profiling techniques can also be used in several other areas

such as marketing, location-allocation analysis, political campaign/fund raising, real estate development, environmental health, archaeology, and so on.

One very important fact that must be kept in mind is the existence of a massive infrastructure (such as Echelon) that is classified and controlled by the government for surveillance purposes. Although the project for total information awareness (TIA) was stopped due to strong public opposition, the government's capability to conduct surveillance has vastly improved with the passing of the Patriot Act following the events of September 11, 2001.

The vastly improved technical capabilities in real-time tracking have led to diverse applications, such as tracking children, the elderly, Alzheimer's patients, animals, employees, students, and those on parole. It is these diverse applications that have created many new legal and ethical issues for us to ponder.

Geospatial Technologies and Society: Legal and Ethical Issues: As demonstrated by several high-profile lawsuits and news reports involving the wide-range applications of geospatial technologies in society, legal, and ethical issues have increasingly been on the public radar screen. There have been calls for a broader public debate and dialogue on these issues in order to develop new legal and ethical guidelines for geospatial technology practices in this new, pervasive computing environment with massive surveillance capabilities. To begin with, a distinction between legal and ethical issues should be helpful.

Legal versus Ethical Issues: Human conduct in society can be classified as legal or illegal (the circle in Figure 1). We also judge people's conduct as ethical or unethical (the rectangle in Figure 1). Under normal circumstances, a clear distinction can be made between legal and illegal and usually also between ethical and unethical conduct in society. Each society has set up its own rule of laws that bans certain behaviors. Violations of laws are subject to sanctions imposed by the judicial system. Ethics refers to values that deal with human conduct or practices with respect to the rightness of certain actions and to the goodness or badness of the motives and ends of such actions. Each society has its rule of ethics and morality, which are widely accepted by that society but not clearly coded into law.

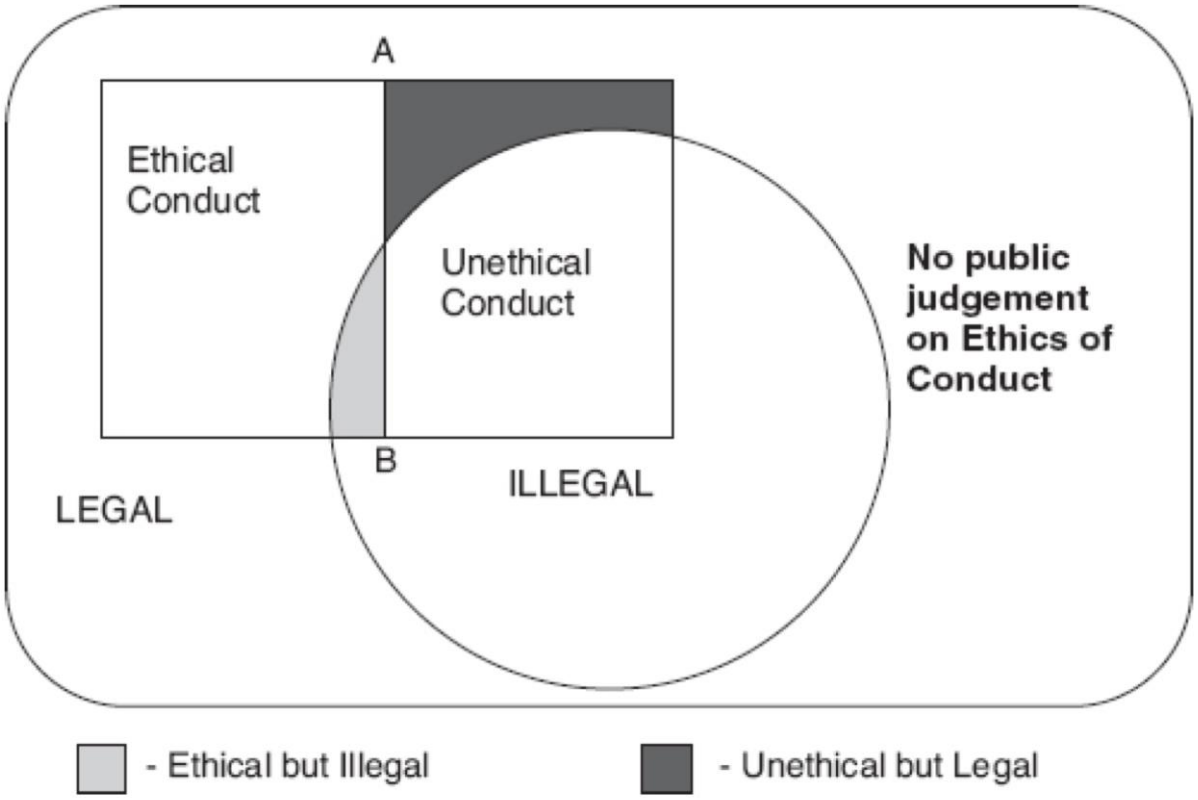


Figure. 1: Legal and Ethical Dimensions of Societal Conduct

Two grey areas complicate the legal versus ethical behavior issue in society. Certain human behaviors are illegal but ethical, whereas some others are legal but unethical. For example, to prevent a murder from happening, one may break the speed limit or break into somebody's house. To some pacifists, the use of geospatial technologies on the battleground is regarded as unethical, but its use is legal in most cases except when geospatial technologies are used in war crimes such as committing genocide or purposefully targeting civilians. Similarly, to some environmentalists, using geospatial technologies to facilitate oil drilling in environmentally sensitive areas (such as Alaska's wildlife refuge) may be legal but unethical. These distinctions are helpful when we discuss the legal and ethical issues of geospatial technologies. But in reality, as Olson (2006) so vividly documented, there exists a vast murky terrain of moral limits in spying for the purpose of national security. The same moral dilemmas, although perhaps at a different intensity level, also exist for the general use of geospatial technologies in society.

Major Legal Issues: Recent media coverage on legal issues relating to geospatial technologies has focused predominantly on tracking people and invasion of privacy, but the legal issues of geospatial technologies are broad and complex. In general, all legal issues related to applications of geospatial technologies are concerned with collection, ownership, access, retention, use, and dissemination of georeferenced data at either individual or collective levels. Major legal issues relating to geospatial technologies can be roughly grouped into three categories:

(1) privacy and data accessibility issues;

(2) intellectual property, copyright, and data licensing issues; and

(3) international law issues.

Privacy and Data Accessibility Issues: At the individual level, the possible invasion of privacy has been a growing concern owing to the growing use of geospatial technologies to track people and commodities in real time. Traditionally, privacy has been defined as an individual's right to be left alone. Over the past century, extraordinary technological development has dramatically redefined the boundary and the domain of what is normally considered as a private realm. The meaning of privacy has also changed from the right to be left alone, to the right to enjoy anonymity, to the right to control information about oneself, and so on. The recent development of geospatial technologies has moved locational (spatial or geographical) privacy to the forefront of privacy concerns. Purely locational information in terms of latitude/longitude or other types of coordinates (site information) may not be that meaningful, but people can make a reasonable inference about the surroundings of a particular location (situation information), which could be embarrassing or harmful. This is in large part why most people would prefer their whereabouts to remain private. For example, each year, one million American women and half million American men are being stalked (http://www.ojp.usdoj.gov/bjs/abstract/svus.htm), and geospatial technologies can play a very important role in stalking.

In terms of legal protections, the Fourth Amendment of the US Constitution provides that: ″The right of the people to be secure in their persons, houses, papers, and effects, against unreasonable searches and seizures, shall not be violated, and no Warrants shall issue, but upon probable cause, supported by Oath or affirmation, and particularly describing the place to be searched.” Constitutional protections for privacy, derived primarily from the Fourth Amendment, restrict government intrusion into our personal life through searches of persons, personal space, and information. For law enforcement officials, a search warrant is usually required before a private property can be search or seized. Although, in general, the fourth Amendment places restrictions on government intrusions into the private realm of ordinary citizens, it has not been interpreted to provide an effective means of protecting physical and locational privacy outside of the home or other quarters. In the seminal case Katz v. United States (1967), the United States Supreme Court held that government eavesdropping of a man in a public phone booth violated a reasonable expectation of privacy because the Fourth Amendment protects people, not places (Herbert, 2006). The Supreme Court has interpreted the Fourth Amendment as protecting individuals from government intrusions without a warrant only where the individual has an objectively reasonable expectation of privacy. The reasonable expectation standard has been adopted by the state courts when interpreting state constitutional and common law protections of privacy. However, in a recent case involving Google™ , a Pennsylvania judge recently dismissed a law suit against Google™ for posting some very private photos on Google Earth™ Street View.

As a worst-case scenario, some scholars have also contemplated the possibility of geoslavery in this age of ubiquitous computing. The growing applications of geospatial technologies, especially through the development of human tracking devices and various kinds of LBS, has introduced a new potential for real-time locational control and monitoring that extend far beyond privacy and surveillance per se. Scholars have warned that society must address a new form of slavery characterized by location control –

geoslavery, now looming as a real, immediate, and global threat. According to Dobson and Fisher, geoslavery refers to ″a practice in which one entity (the master) coercively or surreptitiously monitors and exerts control over the physical location of another individual (the slave)”. With the current geospatial technologies readily available and affordable (US300–500), an individual can routinely control the time, location, speed, and direction of another individual for each and every movement, even without the permission of the individual being monitored. The fact that child slavery, sex slavery, and other abusive behaviors (such as stalking) are still rampant worldwide (e.g., http://www.iabolish.com/ slavery_today.htm) begs one to ponder where the increasing use of geospatial technologies and location- aware computing will lead us in the near future. The potential of geoslavery has raised the issue of whether locational privacy should be universally protected as a fundamental human right. Although legally speaking, the Thirteenth Amendment of the US Constitution, which states: ″Neither slavery nor involuntary servitude, except as a punishment for crime whereof the party shall have been duly convicted, shall exist within the United States, or any place subject to their jurisdiction,” has clearly outlawed slavery since 1865, recent incidents involving individuals serve as painful reminders of the potential for geoslavery.

Although the Fourth (and possibly the Thirteenth) US Constitutional Amendments have been invoked in legal cases regarding the use of geospatial technologies, legal scholars have argued that it is unlikely that workable limitations on the use of human tracking devices will grow out of criminal appeals under these Amendments. Many legal issues, such as who can track whom, under what circumstances, and whether a warrant is needed (in the case of police tracking citizens) also have to rely on other federal and state laws.

Several federal legislations have been cited in recent legal cases. While the Electronic Communication Privacy Act 1986 protects against unauthorized interception and disclosure of electronic communications, it excludes tracking devices. However, the Wireless Communication and Public Safety Act 1999, explicitly protects location information in wireless devices, requiring customer approval for disclosure. This protection does not extend to deriving location information from communication devices. Transaction information such as telephone numbers is not protected (Smith v. Maryland, 1979), but providers are prevented from releasing information that discloses the physical location of an individual (CALEA, 1994/2000; US Telecom v. FCC, 2000). However, using mobile communication devices as tracking devices to derive location information is not constitutionally prohibited (US v. Meriwether, 1990; US v. Knotts, 1983; US v. Forest, 2004), as courts have ruled that individuals using cell phones, beepers, and pagers do not have a reasonable expectation of privacy when moving from place to place (although this interpretation continues to be challenged). Several related federal regulations, however, have been enacted: Telecommunication Act 1996; Children's On-line Privacy Protection Act; Children's Bullying law; Privacy for Consumer and Workers Act 1993; and the Video Voyeurism Prevention Act, as well as other legislations aimed at eavesdropping and Internet websites.

Recently, however, the Patriot Act 2001 has nullified some of these protections, granting broad authorities for government surveillance, including the ability to use roving wiretaps, which has caused grave concerns to both the public and legal scholars. The Patriot Act has vastly increased government power for surveillance (in some cases even warrantless). Taipale (2007) describes the nature of modern communication networks and certain related technology developments, and examines how three situations – transit intercepts, collateral intercepts, and automated monitoring – cannot be accommodated by

the Foreign Intelligence Surveillance Act (FISA) as currently constituted. It remains a legal challenge to fix foreign intelligence surveillance so that it preserves existing Fourth Amendment principles and protections while still addressing these failures. To get beyond backward looking recriminations, we need to craft new progressive consensual solutions.

Invasion of privacy due to the use of geospatial technologies can also be dealt with through common law and state constitutions. Tort laws are often invoked. A tort is a wrongful act or damage (not involving a breach of contract) for which a civil action can be brought. Following the doctrine established by Warren and Brandeis (1890), there are four kinds of privacy torts:

- Misappropriation of one's likeness – use of a person's name, likeness, or identity for trade or advertising purposes without consent.
- Intrusion upon a person's seclusion – a physical, electronic, or mechanical intrusion into someone's private space. This is an information-gathering, not a publication, tort. The legal wrong occurs at the time of the intrusion; no publication is necessary.
- Public disclosure of embarrassing private facts – publication of non-newsworthy, private facts about an individual so intimate that they outrage the public's sense of decency, or that would be highly offensive to a reasonable person (true defamation).
- Publicity in false light – publication of false, highly offensive (but not necessarily defamatory) information about an individual.

However, the public disclosure tort is limited by the clause that if an event takes place in a public place, the tort is unavailable. The courts have generally ruled that a person traveling in public places voluntarily conveys location information. But courts have also recognized that a person does not automatically make public everything he or she does merely by being in a public place. Most states give common law or statutory recognition to some or all four of the privacy torts.

According to Herbert and Tuminaro (2008), case law has interpreted these locational privacy rights more specifically, examining intrusions of technology into the private sphere, government searches that are technologically enhanced, and the use of mobile devices and telecommunication information to derive locational information. While Fourth Amendment protection does not extend to that which is knowingly disclosed to the public, the courts have ruled that the use of technologies not available to the general public can violate the privacy one reasonably expects (Kyllo v. US, 2001). However, the courts have also shown a willingness to allow law enforcement to use technologically enhanced means for searches, including flying over properties such as a fenced backyard (California v. Ciraolo, 1986), a greenhouse (Florida v. Riley, 1986), or an industrial plant (Dow Chemical v. US, 1986), suggesting that the open fields doctrine brings no reasonable expectation of privacy.

In summary, legal protection for location privacy in the USA is inconsistent and sectoral, providing coverage only under certain situations and for specific technologies. Recently, legal public privacy issues raised by Nissenbaum (1998) and the further development of geospatial technologies have certainly added quite a bit of urgency to this issue. Conflicting rules exist, such as the need to obtain a warrant for police to start tracking somebody, despite the lack of legal protection for privacy in public.

Intellectual Property, Copyright, and Data Licensing Issues: In addition to privacy issues, recent advances in geospatial technologies have also raised many challenging issues related to copyright, liability, and intellectual property rights on diverse geographic

information. Under the current culture of mashing-up practices, which is part of the larger emerging remixing culture, ″who legally owns the geospatial data” emerges as a burning issue for further discussion and clarification. The recent development of VGI poses new interesting questions about data ownership,

intellectual property rights, and copyright, as recently demonstrated by the FacebookTM data ownership dispute (see http://www.japantoday.com/category/technology/view/facebook-does-about-face-in-content- ownership-dispute).

Licensing of geographic data and works has increasingly become a common practice because of the limited protection afforded by copyright and other intellectual property doctrines in the digital environment. License or licensing of geographic data or a geographic work means a transaction or arrangement (usually a contract, in which there is an exchange of value) in which the acquiring party (e.g., the licensee) obtains information with restrictions on the licensee's rights to use or transfer the information. More and more data providers also have turned to technological means to control access and copying, measures that are reinforced by the Digital Millennium Copyright Act, for works that have at least some copyright protection. Moreover, courts have upheld contracts or licenses that limit the uses that a licensee can make of data, or that prohibit further distribution. Data providers' rights are likely to be further strengthened if Congress adopts database protection.

Federal agencies almost always distribute geographic data at or below marginal cost of distribution. Cost recovery has been the norm in dealing with spatial data in Europe and it has held GIS development back. In the USA, Landsat pricing has also attempted to follow the cost recovery path, which has held back the development of remote sensing. Since the 1990s however many state and local governments have experimented with the distribution of data using licenses to generate revenue from them. As we move further into the ubiquitous computing age of the twenty-first century, many of these entities have concluded that fee programs (1) cannot recover a significant fraction of government data budgets, (2) seldom cover operating expenses, and (3) act as a drag on private-sector investments that would otherwise add to the tax base and help grow the economy. The use of licenses to provide data to users may, however, be useful to enforce proper attribution, minimize liability, enhance data security, and formalize collaboration.

Licensing has become commonplace because of the realization that many geographic data, as opposed to geographic creative works, are difficult to protect through copyright alone. There have been growing concerns over potential liability and a desire to limit liability through explicit license language. Sharing costs through various data maintenance partnerships has also become common practice.

This has facilitated a shift away from supplying distinct datasets to providing access to databases, and the rise of business models that stress multiple subscribers despite the reality of digital networks and media that allow others to distribute perfect and inexpensive copies.

Confusion and uncertainty have arisen in recent years as a result of a proliferation of nonstandard licensing arrangements. The geospatial community has recognized the difficulty of designing licenses that can (1) track the legal, economic, and public interest concerns of different levels of government, and (2) accommodate all sectors of the geographic data community. There also exist no effective license tracking and

enforcement mechanisms. Different sectors of the geospatial community also have different practices and standards in the licensing process.

The wikification of GIS has also raised another important legal issue on who is qualified to create geospatial data. In January 2007, the Management Association for Private Photogrammetric Surveyors (MAPPS) filed a lawsuit seeking to limit competition for federal mapping contracts of nearly every type, including GIS services, to firms of licensed architects, engineers, and surveyors alone. In June 2007, Judge T.S. Ellis III of the US District Court in Alexandria, Virginia, ruled against MAPPS, finding that MAPPS failed to "establish that an injury in fact was suffered by the individual [licensed] surveyors or their firms" (http://www.ucgis.org).

This is a significant legal victory for the continuing democratization of GIS, which will hopefully ensure all qualified professionals – not just licensed engineers and surveyors – can compete for government contracts related to mapping and GIS activities. Recent innovations in technologies have drastically flattened the learning curve for geospatial and mapping technologies. The development of Google Maps™/Google Earth™ and Microsoft ′s® Virtual Earth® , along with their precursors Mapquest, Yahoo Maps, Multimap, StreetMap, and so on, have democratized the application of massive online geospatial information. Additionally, the new wave of technological innovations has even democratized the production of maps and online geospatial information. The accelerated democratizing process for mapping and GIS has put powerful mapping technologies into the hands of the masses, which now can perform rather complex mapping tasks (once requiring years of training) with little or no training at all. Although Judge Ellis' ruling in the case of MAPPS v. US Government has been widely applauded by the geospatial community, the fast growing collaborative mapping by amateurs (or citizen cartographers) does raise new questions and concerns about the authority and trustworthiness of geographic information production.

Drawing on an analogy of the tragedy of the commons in the environmental domain, Onsrud (1998) warned of a possible tragedy of the information commons unless innovative mechanisms for sharing information and licensing geographic data are developed. The recent democratization of geographic data collection and dissemination in the age of Web 2.0 further complicates the liability issue of geographic data information. Obviously, the wide-ranging applications may be disadvantageous to some people, such as users of the software or data or those affected by decisions taken on the basis of GIS applications. Liability is a creation of the law to support a range of important social goals such as avoidance of injury, encouraging the fulfillment of obligations established by contracts, and the distribution of losses to those responsible for them. Generally speaking, liability of GIS is related either to contract liabilities (warranties/implied vs. defined) versus tort liabilities (negligence, fraud, and product liability).

Liability in data, products, and services related to GIS is likely to be determined in most instances by resort to contract law and warranty issues. If decisions are made based on geographical data or products produced by someone other than the user, there will always be liability exposure. Minimizing losses for users of geographical data products and reducing liability exposure for creators and distributors of such products is achieved primarily through performing competent work and keeping all parties informed of their obligations. But new data-licensing practices, value-added operations, plus volunteered geographic information via mashing up and wiki sites have made it increasingly difficult, if not entirely impossible, to track the creators and distributors of geographic data.

Establishing liability in case something goes wrong is thus becoming even murkier. Recent road accidents also raised the issue of whether GPS or navigation systems should be blamed for fatal crashes.

International Dimension : When Google Earth™ was first launched in 2005, several countries, including India, China, Pakistan, and Israel, immediately expressed security concerns posed by the high-resolution satellite imagery taken over their sovereign territory, which renewed discussions on the legal issues of geospatial technology at the international level. In fact, such have been a concern of the international community since the early days of remote sensing technology in the 1960s, as geospatial technologies have always played an important role in international affairs.

The basic legal framework for all space activities is provided by the 1967 Outer Space Treaty, signed by major countries in the world with space technology capabilities. This treaty ensures the freedom of exploration and use of outer space by all states, including for satellite remote sensing. The treaty further articulates the principle of non-appropriation of outer space by any single state. This treaty also makes it clear that any limit to the freedom of exploration and use can be established only at the international level, that is, by the community of states via treaty provisions or, as the case may be, by customary international legal rules. Finally, the treaty provides for the application of general international law to outer space, in particular by establishing general principles such as the freedom of information gathering from outer space.

The United Nations Declaration on Principles Relating to Remote Sensing of the Earth from Outer Space, Resolution 41/65, adopted on 3 December 1986, sets out the main legal principles (15 in total) specifically pertinent to remote sensing. Resolutions passed by the UN General Assembly do not per se constitute binding legal documents; however, they may over time evolve into reflections of customary international law. Resolution 41/65 was adopted by consensus, and in any case UN General Assembly Resolutions carry considerable weight in the political/moral sphere, so that this resolution may indeed be considered customary law.

The key principles contained in the resolution deal with the issue of access to data gathered by remote sensing activities for land-use purposes, in particular, by states other than the one(s) generating the data in the first place. Here, Principle IV provides for the conduct of activities on the basis of respect for the sovereignty of so-called ″sensed states.” Principle V calls for offering opportunities of cooperation to sensed states, and Principle VII requires so-called ″sensing states” to make technical assistance available to other interested states on mutually agreed terms. Most importantly, however, Principle XII provides for a right of access by the sensed state to data concerning its territory ″on a non-discriminatory basis and on reasonable cost terms.” While these two qualifications already allow for considerable flexibility for sensing states ultimately to disallow sensed states access to certain data, it is also clear that the sensed state has no right of precluding its territory from being sensed, nor any right of exclusive, or even priority access to such data. In the last resort, freedom of information-gathering has thus prevailed over a principle of sovereign control over data regarding one's own territory.

In terms of obligations binding on states concerned, Principle X lays down the need for states to convey relevant information regarding threats to the ″Earth's natural environment” to other states concerned; and Principle XI calls upon states in the possession of relevant information regarding natural disasters to duly inform other states concerned. Principle VIII furthermore envisages a key role for the United Nations: it

″shall promote international cooperation, including technical assistance and coordination in the area of remote sensing.” Once again, freedom of information-gathering reigns supreme over data control.

The above framework, being very general, already raises a number of legal issues at the highest level when it comes to applying it to the ″real world” of satellite earth observation. Two of these will be briefly touched upon as generic issues requiring treatment before moving on to legal details. Such details would namely also involve particular intellectual property rights issues pertaining to satellite data, compensation for damage caused by erroneously interpreted data, the potential value as evidence in court cases, and a number of other matters, all involving specific legal regimes and questions.

The two ″real world” issues concern international responsibility and liability, respectively in specific cases of involvement of intergovernmental organizations and private entities as categories of players in addition to that of the states. First, under Article VI of the Outer Space Treaty, states are responsible for national activities in space, even if conducted by non-governmental entities, and for ensuring that these activities conform to the law. Second and along similar lines, under Article VII of the Outer Space Treaty and the 1972 Liability Convention, states are specifically liable for damage caused by space objects. Both are, therefore, clearly focused on states as ″undertakers” of space activities, a focus which made sense historically but is increasingly subject to discussion.

The role of intergovernmental organizations results in some particular ramifications of responsibility and liability. As to state responsibility, it also applies when activities are carried on in outer space by an international organization, although in such cases jointly with the responsibility of the international organization itself. As a result, member states of intergovernmental organizations are effectively prevented from hiding behind these organizations in the case of their earth-observation activities violating applicable rules of international law; it is their duty and responsibility to ensure that the organizations themselves do not undertake any such violating activities.

As to liability, under the 1972 Liability Convention, intergovernmental organizations equally enjoy a secondary status effectively allowing them to qualify to some extent as liable entities, and a similar construction under the 1975 Registration Convention allows them to themselves register satellites and exercise concomitant competencies over them. The European Space Agency (ESA) actually enjoys the relevant status, as it has deposited relevant Declarations in respect of both conventions, but for most organizations, any liability would revert directly to individual member states.

As far as the liability stemming from geospatial data is concerned, this is still a murky terrain in international law. Some legal scholars have argued that international liabilities regarding geospatial data are most likely handled by international agreements and frameworks such as the General Agreement on Tariffs and Trade (GATT) developed by the World Trade Organization (WTO). Dispute resolution over international liabilities of geospatial data may also be addressed by various existing and proposed EU laws regarding electronic databases, or other bi-lateral/multi-lateral agreements such as the North America Free Trade Agreement (NAFTA) or the Mercado Común del Sur (MERCOSUR).

Critics argue that the existing rules of international law regarding geospatial technologies are outdated and no longer can deal with the complexities of their international dimensions. Both the Outer Space Treaty and the UN Resolution of 41/65 reflect the

legacy of the Cold War with heavy emphasis on states as players. Their dominant concern is military/national security instead of commercial goals. They have also been criticized as overtly favoring those developed countries with space capabilities, whereas the rights of developing countries are not properly respected according to the international rule of law.

Ethical Issues: As indicated earlier, not all of the social issues brought about by the advances in geospatial information science and technology can be resolved according to the rule of law. Some of these issues fall into the realm of ethics and moral judgment. Ethics deal with society's moral code on human behavior and practices in terms of right and wrong, which varies greatly according the culture, history, and customs of the country concerned. Generally speaking, discussions on ethics can be conducted at three levels: normative, meta-, and descriptive/applied. Normative ethics deals with issues related to what should be considered as right or wrong behavior/practices in society, whereas meta-ethics is concerned with the ontological foundation and justification for the normative practices. Descriptive/applied ethics concentrates primarily on what specific actions we should take under specific circumstances. Some scholars have raised and discussed ethical issues pertaining to GIS from normative and meta-ethical perspectives, but for the general public, the applied/ descriptive perspective on ethics is perhaps more relevant. We have yet to define what actions are acceptable and under what circumstances our use of geospatial technologies is ethical and moral.

One particular ethical dilemma we face is the so-called exterior surveillance vs. interior sousveillance. Recent technological advances seem to point to a paradoxical trend involving the general public and the rapid diffusion of geospatial technologies. On the one hand, millions of Internet users worldwide voluntarily contribute very large amounts of information by the hour (if not by the minute) using Web 2.0 technologies in different formats of user-generated content. The blogs, photos, videos, and twitss contributed by users on the Web often expose people's lives in excruciating detail. There is a vast literature in psychology about this aspect of human nature, which is closely related to exhibitionism and voyeurism. In fact, most people not only want and enjoy surveillance, but also play with it and use it for comfort (McGrath, 2004). On the other hand, we have repeatedly seen headlines in various news media on the growing public concerns and outcry about the danger of surveillance, invasion of privacy, and a looming geoslavery on the horizon. Although fragmented studies and reflections have been reported, there exists no comprehensive study so far linking these two separate lines of inquiry to address this love–hate reaction by the public to surveillance in general, and geosurveillance in particular. We need more research and attention to this area, which may facilitate the development of applied ethics for geospatial technologies.

The dilemma seems to derive from the fact that human existence is often characterized by the paradoxical desires of trying to be both private and public. The question is when, where, how, and whether the parties involved have the choice of disclosing or not disclosing. On the one hand, we are all afraid of the darker scenarios of repressive obsession and the invasion of privacy through the relentless logistics of data gathering and database linkages. Dystopian depictions of a future totalitarian state run by a super-panopticon is also too Orwellian to be real. On the other hand, the seemingly new fascination with certain forms of surveillance as a source of pleasure and entertainment is manifested in the increasing popularity of webcams, the proliferation of claims to real-time/live broadcasting, and the global success of the reality TV genre, which has resulted in the dramatic proliferation of surveillance both as subject matter and as narrative

structure in contemporary cinematic production. The risks of aestheticizing surveillance can potentially trivialize its irreducible and all-too stark political dimensions.

Another ethical issue is related to the so-called first law of geographic information: information is often the most scarce when it is needed the most. Have the applications of geospatial technologies helped to narrow or widen the digital divide? The new surveillance infrastructure, of which geospatial technologies are an integral part, mediates the production of social knowledge and action toward individuals. The potential uses of locational infrastructure redistribute the power to negotiate the meanings and uses of public places. Non-reciprocal visibility is one of the greatest inequities in contemporary surveillance. Who is being constantly surveilled? The news reports seem to point to the young, the sick, the elderly, and the vulnerable.

The on-going war on terrorism raises another ethical dilemma. High-resolution satellite images available on Google Earth™ have reportedly been used by terrorists in Yemen in 2006 and insurgents in Iraq in 2007 to plan attacks on allied troops. True, committed terrorists could find all this information in most public libraries, but the increasing availability of online geospatial databases has made some of the sensitive information a lot easier to access. In other words, by making more geospatial information available online, we have inadvertently created an infrastructure that can be used counterproductively by terrorists to plan and launch attacks against us.

In his classic essay ″The Tragedy for the Commons,″ Hardin (1968, p.1243) somberly warned ″ruin is the destination toward which all men rush, each pursuing his own best interest in a society that believes in the freedom of the commons. Freedom in a commons brings ruin to all.″ This raises the question, should society impose certain limits and guidelines in terms of who can collect, access, use, retain, and disseminate geospatial data?

Seeking Remedies: Discussions and Prospects: Evidently, the recent developments in geospatial technologies and their wide-ranging applications have raised a series of challenging legal and ethical issues. Although existing laws and regulations can be applied to some limited extent, we need a combination of legal, ethical, and technical approaches in order to address these issues effectively.

New Legislation: Most legal issues regarding the use of geospatial technologies in society revolve around the issues related to geospatial data/information at the individual or collective levels, and include: (1) data collection; (2) data retention; (3) data access; (4) data use and integration with other information; (5) data dissemination; and (6) data ownership and licensing. Comprehensive legislation is needed to clearly address these issues at local, national, and international levels. The European Union framework, as implemented in the Netherlands, strikes a balance between protecting consumer privacy versus offering adequate services, while at the same time the new legal frameworks are also widely accepted by the general public. In the USA, former North Carolina Senator John Edwards initiated new federal legislation on locational technologies in 2003, but the new law was not brought to the Senate floor for a vote due to his subsequent vice-presidential nomination in the 2004 presidential campaign. Generally speaking, the USA has taken a more laissez-faire approach to markets, which tends to restrain government, whereas EU tends to regulate third parties.

A core concept that much of the new legislation hinges upon is locational privacy, which suggests individuals have rights to their signature in space and time and can determine

when, how, and to what extent location information is communicated to others. For further legal protection Sui (2006b) proposed that location be treated as an integral part of a person's identity, as where we are often reflects and defines who we are. By treating location as part of identity, Sui (2006b) argued that many existing laws regarding identify theft can be invoked when a person's location information is collected, used, and disseminated without the person's permission.

In recent years, more than 13 US states have passed laws restricting RFID adoption and application. Texas, for example, passed laws prohibiting school districts from requiring students to use an RFID device for identification. Wisconsin made it illegal to implant RFID chips into human bodies. Also, New Mexico and Tennessee require the disclosure of RFID chips to consumers and the removal or deactivation of tags at the point of sale of RFID-chipped merchandise (http://rfidprivacy.mit.edu/access/happening_legislation.html).

There also have been efforts in recent years to develop measures of self-regulation by industry. Although industry self-regulation is a welcome step toward protecting personal privacy, these rules and regulations by service or data providers often focus on relieving themselves of legal liabilities, thus avoiding potential law suits in case something goes wrong. It is also hard to enforce those industry self-regulations.

Many businesses offering LBS or geospatial information have increasingly realized the importance of the legal and ethical issues that a suite of powerful geospatial technologies has brought to individuals and society. Industry leaders have recognized that safeguarding sensitive personal information is not only important to consumers, but also of paramount importance for the sustainable growth of their business. Most LBS or geospatial data providers have developed their own privacy policies and protocols posted on their web sites, most of which warn users of the potential risks of using their data or services.

One particular area that has attracted much public attention in recent years is the legal limit of an employer's right to conduct surveillance on employees. As the boundary between work and non-work is increasingly blurred in the digital economy, how to track employees for their productivity, although understandable and legitimate, has caused considerable privacy concerns in recent years. Furthermore, inspired by Garrett Hardin's tragedy of the commons thesis, Onsrud (1998) argued for the existence of what he called the information commons. Drawing from experiences in developing laws to protect the environmental commons, he proposed to develop new legal frameworks for the information commons.

New Ethics: Legal remedies are expensive and notoriously slow, and not every potential problem caused by geospatial technologies can be litigated. Therefore, in addition to legal solutions through new legislation, scholars have also been calling for the development of new ethics rules and social norms at both the individual and societal levels suitable for the age of pervasive computing. In addressing many of the social issues brought by new technologies, new ethics and moral practices are perhaps more effective, because as humans we are more likely to be seduced by new ethics rather than coerced into compliance with new laws.

To resolve many social problems, Dodge and Kitchin (2005) advocated a new ethics of forgetting, which clearly articulates a new set of rules on ″how” and ″when” to ″forget,” and even ″delete,” the massive electronic information in the age of pervasive computing. The rapid development of pervasive computing in general and geospatial tracking in

particular has led to the widespread sousveillance, which complements surveillance, through the development of life-logs. We now have a new cyber-infrastructure for socio-spatial archives that can document every action, every event, every conversation, and every material expression of an individual's life. A new ethics of forgetting needs to be developed and built into the development of life-logging technologies. Rather than seeing forgetting as a weakness or fallibility, Dodge and Kitchin (2005) argued that the new ethics of forgetting could be an emancipatory process that will free pervasive computing (of which geospatial technologies are part of) from burdensome and pernicious effects.

Recently, Google™ has already started a new business of blurring or deleting sensitive targets on Google Maps™ or Google Earth™. Although the benefits of a new ethics of forgetting cannot be denied under certain circumstances, it is not always possible, or even desirable, to adhere to forgetting as a new social norm. Inspired by Asimov's "Three Laws of Robotics" (Table 2), Durocher (2002) formulated a set of three laws of LBS (Table 3), which he contends that the LBS industry should adopt. Overall, LBS should have ethical laws regarding (1) its use during emergency situations; (2) its voluntary status; and (3) the appropriate/beneficial use of the locational data.

Table 2: Asimov's Laws of Robotics

First Law of Robotics:
A robot may not injure a human being, or, through inaction, allow a human being to come to harm.
Second Law of Robotics:
A robot must obey orders given to it by human beings, except where such orders would conflict with the First Law.
Third Law of Robotics:
A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.

Table.3: Durocher's Laws of LBS

First Law of LBS:
Location, through its availability or non-availability, must not allow a human being to come to harm.
Second Law of LBS:
The availability of one's location must be in one's complete control, except where such control would conflict with the First Law.
Third Law of LBS:
The providers of location-based services must be allowed to create a profitable business from these services as long as such business does not conflict with the First or Second Law.

Since its original publication in a short story called "Runaround" in 1942, Asimov's three laws of robotics have been continuously debated and fine-tuned. Although still controversial, several extensions have been made, Asimov's laws have been widely

accepted as a reasonable guide to discuss the moral issue of robotics. Even Asimov himself admitted that ″there was just enough ambiguity in the three laws to provide the conflicts and uncertainties required for new stories, and to my great relief, it seemed always to be possible to think up a new angle out of the sixty-one words of the three laws”.

Although significant fine-tuning is needed, Durocher's three laws of LBS offer a reasonable guideline for the use of LBS in the near future – provided that an enforcement mechanism can eventually be established. The first LBS law addresses the requirements of LBS in emergency situations. It is consistent with enhanced 911 (E911) services as mandated by the new FCC regulation. It is reasonable to expect improved emergency services if all 911 calls are locationally explicit. The first law of LBS also requires that no services should put mobile users in danger.

The second law would ensure that LBS services are voluntary, and therefore that privacy should be preserved for individuals subscribing to these services. Under normal circumstances, a subscriber should be able to prevent others from locating him or her. But totally complying with this could also put the user at risk, since in emergency situations it might be impossible for the user to provide all the necessary life-saving authorization-Alaso, in some cases, the police will want to (and already do) track cellular phone usage to locate dangerous criminals.

Finally, the third law stresses the fact that providing location information alone is not sufficient to sustain business growth. Service providers must find a way to develop the right business models and charge the appropriate fees for the right services. Applications must bring real value that consumers and business users will be willing to pay for. However, the third law also ensures that no business should be able to benefit from the availability of location data to the detriment of a LBS user's right to complete privacy and safety.

As Fisher and Dobson (2003) illustrated in their seven different scenarios regarding the use of LBS (Table 4), the legal and ethical implications of LBS are complex and contingent upon many uncertain parameters in the real world. Nonetheless, I believe that the three LBS laws provide reasonable guidelines for most civilian applications, as tested by the Fisher and Dobson's seven scenarios (Table 4). The ethics of forgetting is only one of the seven possible real world scenarios defining practices that may be viewed as desirable.

Technical Solutions: Steps toward Trustworthy Geospatial Technologies? Legal and ethical strategies for remedying the problems brought about by geospatial technologies are trust- based mechanisms for delimiting unacceptable uses of location information. However, trust can be breached, making sensitive information still vulnerable to unintentional and intentional disclosure. Therefore, the research community also suggests development of technical solutions. A range of previous research on location privacy has addressed the issue of adapting the level of spatial detail in location information as needed to protect an individual's location privacy. This concept is termed spatial generalization by Mascetti and Bettini (2007), but has also been variously termed in the literature as ″spatial cloaking”, ″obfuscation”, the ″need-to-know principle”, and the ″principle of minimal asymmetry”.

Table. 4 Surveillance Scenarios and Laws of LBS

Scenarios	Examples	Legal/Ethical Issues	Laws of LBS
They didn't know where you were	Normal life for ordinary citizens	Personal privacy/ ethics of forgetting	Obeyed (violated if the person is suicidal?)
They know and you want them to	On call, emergency, alibi	Consent	Obeyed
They don't know but you thought they did	Faulty signal, signal blocked, physical density	Ignorence	Violated
They know and we wanted them to	Criminal activity, unethical conduct	Public interest	Ambiguous
They know and you didn't want them to	Nuisance calls, stalking, monitoring	Geo-identity Theft	Violated
They know and we thought we wanted them to	Abusers, hostage takers	Coercion	Violated
They know and can physically keep you there	Forced labor or domestic abuse	Geo-slavery	Violated

Generally, two major strategies have been well-developed and adopted: anonymity and obfuscation. Anonymity is often regarded as one of the privacy-sympathetic technologies (PST). Anonymity detaches or removes an individual's locational information from electronic transactions. Anonymity is normally quite effective in protecting individual privacy. However, with recent advances in data mining techniques, GIS can integrate locational information with other data such as remotely sensed imagery, georeferenced social, economic, and cadastral data, point of-sale data, credit-card transactions, traffic monitoring and video surveillance imagery, and other geosensor network data, allowing identity to be inferred. Obfuscation techniques deliberately degrade locational information, using error and uncertainty to protect privacy, which is part of the privacy enhancing technologies (PET). They also include geographic masking for static data (Armstrong et al., 1999). Duckham and Kulik (2006) extend the obfuscation approach to mobile objects. They also consider ways to counter potential threats from third parties who can refine their knowledge of a mobile object and compromise the obfuscation.

Reactions by the International Community: Facing the threat of freely available high-resolution satellite images in various digital globes such as Google Earth™, Microsoft′®s Virtual Earth® , NASA's WorldWind, and so on, many countries have taken a variety of steps to protect their national interests. According to a confidential report recently issued by the CIA's Open Source Center and made public by the Federation of American Scientists (http://www.usatoday.com/ tech/news/surveillance/2008-11-06-googleearth_N.htm), the following reactions have been reported by the international community in response to the recent advances of geospatial technologies.

- Negotiation – some nations have asked Google™ and other companies to keep certain images off the market. For example, Google Earth™ uses older imagery for several

areas of Iraq based on British concerns about exposing its military sites. Some commercial imagery providers – typically those providing pictures from planes, not satellites – blur sensitive images before they are provided to Google™, usually in accordance with local law or at the request of local authorities.

- Bans – China issued a new government regulation barring websites selling "unapproved" commercial imagery in 2008. Similar rules were also implemented in Bahrain, but the move has been mainly to prevent exposure of elaborate residences and land holdings of the country's rich and powerful.
- Buying in – several countries, such as China and Thailand, are getting into the satellite imagery business themselves, and India sells its spy photos commercially. Many countries without their own satellites have become enthusiastic purchasers of commercial imagery to meet intelligence and security needs, and international demand for high-resolution satellite imagery has been growing steadily in recent years.
- Evasion – many countries have stepped up efforts to conceal sensitive facilities, either by putting them underground or camouflaging them. Others, such as India, have improved their ability to discern when satellites pass overhead, which allows them to conduct sensitive military activities when cameras are not watching. (For more details, see http://www.fas.org/irp/dni/osc/google.pdf).

However, these actions are ad hoc. There is an urgent need for the international community, perhaps under the umbrella of the United Nations, to update the rules and resolutions regarding the use of geospatial technologies at the international level in order to narrow the global digital divide between the information rich versus the information poor countries.

Summary and Conclusion: It is abundantly clear that recent technological advances in geospatial technologies have created a complex set of legal and ethical issues that deserve a broader dialogue in society about their short- and long- term implications. Mark Poster (2004) argued that networked digital information "humachines" should be understood as the central part of the evolving, unavoidable aspect of globalization. The new technological cornucopia tends to erode privacy, create new forms of inequality, and diminish the mechanisms of accountability. Indeed, a broader dialogue is needed to awaken humanity from its technological somnambulism. Whereas these humanchines bring with them countless risks and afford considerable resources for highly dangerous agglomerations of power, they also offer serious points of resistance to those powers and may serve as a base for developing auspicious, decentralized, multicultural global networks.

Technological advances provide us with hope for trustworthy computing that is capable of giving users more secure control of their own personal information, but technical remedies are not sufficient for the legal and ethical challenges discussed in this chapter. We also need broader legal and ethical frameworks that can effectively deal with issues at individual, institutional, and international levels. Similar to the dilemmas brought by bio-tech innovations, how to capitalize on the benefits of geospatial technologies and deter (even diminish) the emergence of a dystopia of Orwellian, or a monster of Frankenstein, proportions remains one of the grand challenges for our technological society. Obviously, we all want to savor the fruits of the latest advances in geospatial technologies without succumbing to their most dangerous temptations. Whether this delicate balance can be achieved is far from clear at this point.

Geographers have long been interested in studying complex issues at the intersection of geography and law, geography and ethics, geography and morality, and the education of the next generation of geographers. The widespread applications of geospatial technologies in society and our individual lives have opened new avenues for intellectual inquiries that will have far-reaching impacts. Geographic information scientists need to work closely with other geographers and with scholars in other disciplines facing similar legal and moral concerns in order to address many of challenging issues reviewed in this part.

Legal Issues Regarding Spatial Data: The main legal issues regarding the spatial (geographic) data, information and GIS technology supported databases in general are related to the three prevailing problem domains:

− Intellectual Property Rights and GIS technology - copyright issues on spatial data sets, topographic and thematic maps, GIS databases, GIS software and applications etc.,

− Privacy Protection and GIS technology - confidentiality protection in GIS databases versus enabling public access to spatial data, personal integrity data and political sensitive data, policy for restrictive disposal and limited access to spatial data etc.,

− Liability and GIS technology - warranty and (legal) responsibility for specified spatial data quality, liability contract problems, negligence, torts and damages, limited recovery strategies for spatial data etc.

GIS Data Dissemination and Intellectual Property Rights

Introduction : Digital spatial data likely to be available in huge quantities that too for countries like India where a billion-plus human population interacts with environment, and its dissemination over the network is a complex and gigantic task in scale and dimension. Integrated information and communication technologies provide tremendous opportunities as well as challenges in data storage, retrieval, analysis and dissemination. Current technological advancements and future forecast that computer networks will be powerful in gathering information rapidly and inexpensively. This leads to the tremendous integration and development of third party- products and also secondary use of transactional data. Geographical Information Systems (GIS) are concerned with spatial data collection, analysis and their use. These inputs are primarily from topographical/ thematic maps, GPS/ ground based observations and aerial and space- borne sensors. Such a digital spatial data generation and dissemination will be effective through convergence of information and technologies from geo-spatial technologies as well as Communication technologies which are broadly grouped into (a) non-spatial (b) spatial and (c) networking/ communication technologies and sub-segments listed below;

(a) Non-Spatial Data Sets (for ex Land Records, MIS and Miscellaneous)

(i) Computerised MIS, Relational Data Base Management Systems

(b) Spatial Data Sets (Basic Digital Vector Data, value- added data Services)

(ii) Remote Sensing/GIS Technology based products

(iii) 3 D GIS and Digital Photogrammetry based products

(c) Networking/Communication Technologies(Dissemination/ administration)

(v) Networking, Wireless technologies

(vi) Computer Integrated Telephony, Real-time applications

Digital Data Ownership and Related Copyright Liabilities: It has been primarily Survey of India, the authenticated government agency all the way responsible for survey, publication and dissemination of printed topographical maps and later spearheaded by National Atlas and Thematic Mapping Organisation (NATMO) through thematic maps. Recent developments indicate that both these agencies have gone the digital way, thus by making available digital data to the interested users. Recent decade witnessed mushroom growth of private agencies/ companies digitizing and selling these map products in the open market. Incidentally the source data is either from SOI/NATMO (in exceptional cases, town guide maps). In some cases (like Eicher city maps) these large- scale maps larger than 1: 25,000/10,000 the source of data were supplemented by limited ground surveys as well as recent satellite images. Then came the authorisation of nine government agencies by the government of India for digitizing/ incorporating the detailed information like heights, contours etc in the commercially available digital map products. Legal ban anyway existed for publication/ dissemination of restricted category topographical maps and large-scale vectorised digital spatial data. Web based digital spatial data dissemination (digitised vector) had to depend upon the client-server computer capabilities and this enabled the user to have indirect access to the digital vector data. Bitmaps or JPEG format maps appear on the users screen with minimal manipulation capabilities, while the original data lies in the server and processing happens in the host-server or web-server that distributes the data.

Legal obligations include applicable sections of official information act, official secrets act and cyber-crime act amended from time to time. Under such scenario, ownership of geographic information, liability issues, legal rights and duties, limitations, responsibilities, code of conduct had to be promulgated and adopted under the legal framework within each countries, worldwide by users, system developers and data custodians. GIS system per se do not fit into any of the specific categories of works whether literacy, dramatics or artistic but yet these are products of human creativity and of great value to the society in all its applications. It has been projected that thin copyright for GIS map products give the ease of copying digital data. Court of law examines the process as well as data as an asset in GIS systems within the framework of the concerned (Cho, 2000).

Digital Data: Current Intiatives and Future Prospects

National Spatial Data Infrastructure (NSDI): The Survey of India primarily has the task of evolving digital vector data (DVD) standards for creation of digital spatial data which forms the back-bone of the proposed national spatial data infrastructure (NSDI). Private entrepreneurs have much more challenging role in terms of data generation, data dissemination, value-added services and so on. With NSDI initiative becoming a near reality within few years, it is paramount to identify the private entrepreneur role within the overall framework and to propagate the efforts. Even though attempts have been made for the past two decades, its necessary to point out that inconsistency still exists in databases generated across India, (especially established by separate agencies like National Informatics Centre through its state and district centres: NIC: DISNICs) by various studies/ research. As a part of initiatives from Indian space research organization (ISRO) and department of science and technology (DST) progress is being reported to

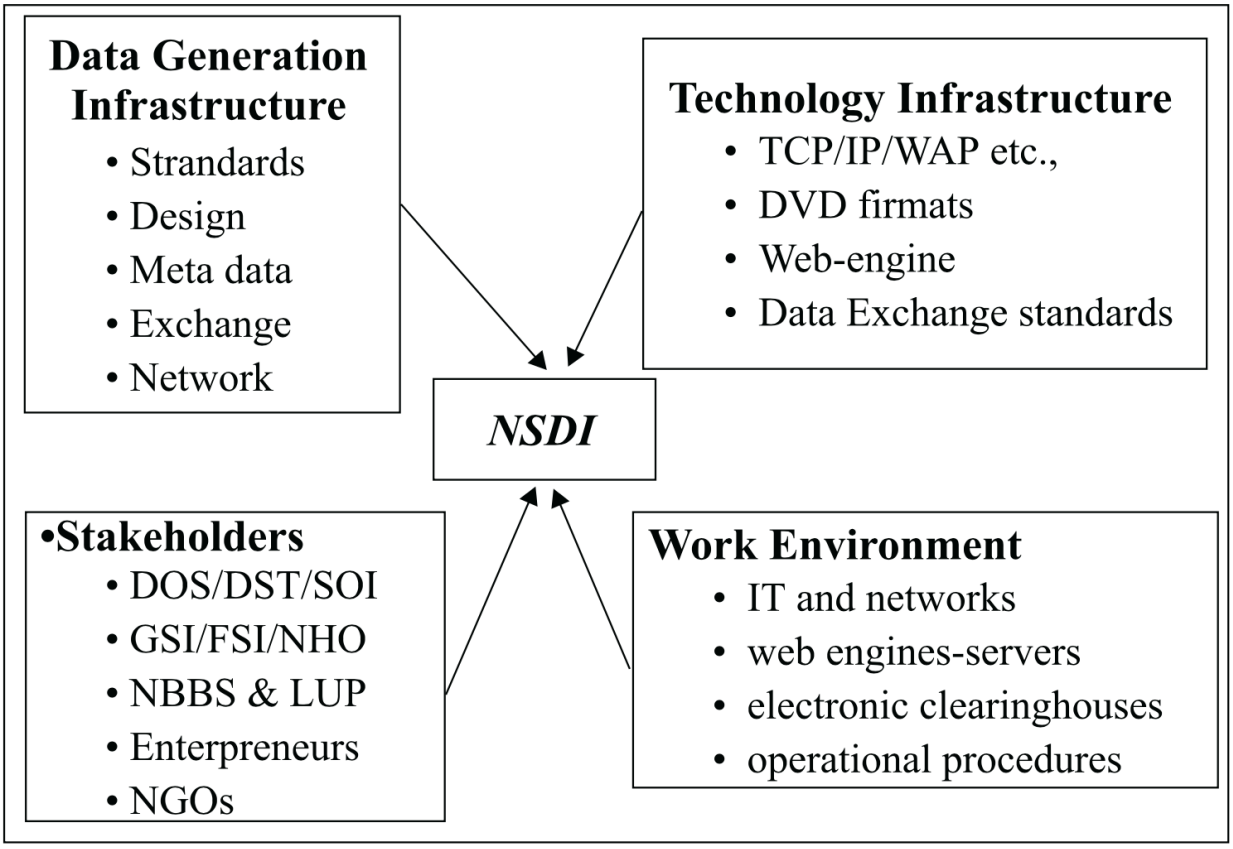
evolve a National Spatial Data Infrastructure (NSDI). NSDI focuses on decentralized approach with main emphasis on:

- Develop and maintain standard digital collections
- Develop common solutions for discovery, access and use of spatial data
- Build relationships among organizations
- Increase the awareness and understanding of the vision, concepts and the benefits

The overall framework that is being planned in NSDI is shown in Chart. 1.

On the basis of approaches for evolving NSDI standards at domain servers, dedicated thematic map server expected to be established for meta-data bases and available for users on demand through single window mechanism or data clearing house for each region/state across India. It is expected that the development of National Spatial Data Information Infrastructure (NII) in USA will enable the convergence of computers and telecommunications on a massive scale and dimension whereas in Japan it will handle voluminous data across network with bi-lingual capabilities of which major contribution comes from private entrepreneurs through NSDIPA. Under such scenario, patents, copyright and IPR issues related to digital spatial data assumes greater relevance and significance.

Chart. 1 NSDI functional inter-linkage components



An Overview of Patents, Copyrights and Intellectual Property Rights

Traditional Trademarks, Patents and Copyrights: Recently IP has been extended to refer a wide range of disparate rights including those known as industrial property such as patents and trademarks.

- literary, artistic and scientific works
- performances of performing artists
- phonograms and broadcasts
- inventions in all fields of human endeavour
- scientific discoveries
- industrial designs, trademarks, service marks and commercial names
- protection against unfair competition
- All other rights resulting from IP activity in the industrial, scientific, literary or artistic fields

Trademarks:

Trademarks Act, 1955 protect the marks used by traders in relation to their goods and services so as to indicate the origin or trade connection of those goods and services.

Registered Designs:

Designs Act, 1906 grants rights in relation to the particular appearance of an article provided its features are novel or original.

Patents:

Patents Act, 1968 protects the rights of inventors in their inventions provided certain threshold requirements have been satisfied such as novelty, inventiveness and utility.

Copyright:

Copyright Act 1968 protects the rights of the authors in their works of original creative effort. Such rights also include the right to reproduce the work and to make copies and the right to present it to the public.

Copyright and GIS: A major reason for singling out copyright for an in-depth treatment is that it imposes on nearly every aspect of GIS as we know it. GIS as applied to geographical data will involve a system of hardware, software and iterative procedures that are designed to support the capture, management, manipulation, analysis, modeling and display of spatially referenced data.
The present task is to analyse the copyright issues as they relate to GIS by examining each functional step in the system where a perceived intellectual property right (IPR) might subsist.

Risk management principles in GIS data/ services and products: In a general way, the development of GIS involves creation and modification of databases, purchase of GIS software, hardware and other peripherals. Selection of data including topographical/ cadastral data, satellite data and other collateral data. The GIS techniques enable us to derive multi-tasking, e.g., preparation and presentation of maps, reports, and considered expert opinion on the analysis/ strategies to assist in the decision-making process. So it is essential to agree that it is experts commitment to provide reliable and accurate and integrated information and analysis. Some of the risk include failure to secure intellectual property rights for GIS and liability for IPR infringement; failure to secure accountability

for a defective GIS and liability for breach of privacy or confidential obligations. Legal uncertainties are involved in contracting out either by or to a government agency. However if products of GIS are considered for provision of services, then different aspects of law come into play, namely liability arising from negligence - a duty of care, the breach of duty of care, causation or proximate cause, and damages. Liability in contract terms may be more limited and narrower in scope.

Guidelines for costing and provision of spatial data: Such policies do not over ride limitations imposed by privacy, confidentiality, liability, intellectual property, national security, other co-operative arrangements, international agreements or statutory obligations.. The development and applications of GIS in a commercial context may involve several legal risks, if ignored could result in a liability and loss for a business or government entity that develops GIS and/or sells, distributes and resells or provides GIS services.

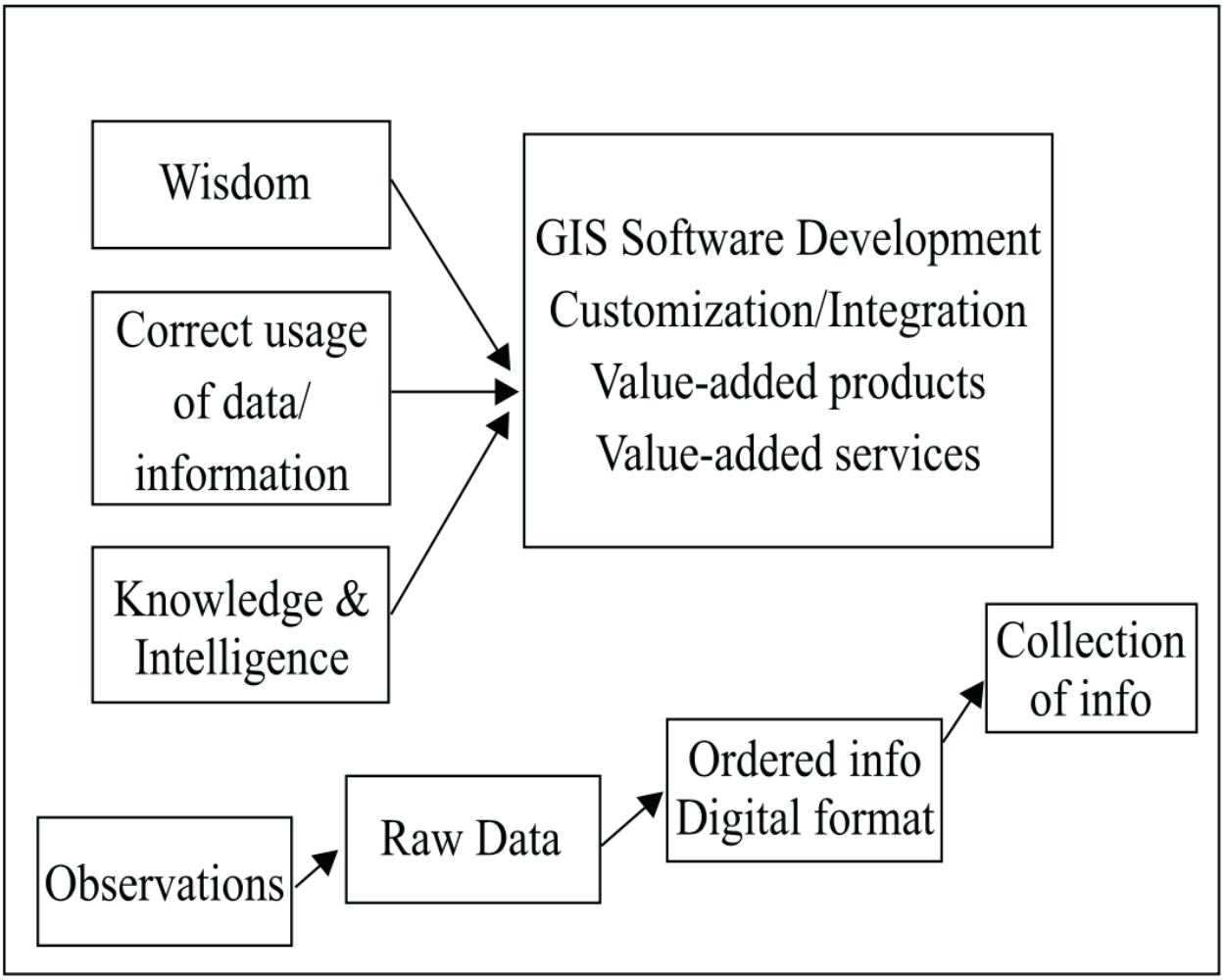


Chart 2: Process of data/information conversion into IP

India Needs IPR Courts: Cyber Law and IPR compliance will be the guiding factors in this complex yet rewarding process. The security and technological risks, involved in this process of transformation, too, will need to be well addressed. Ignorance and non-compliance of Cyber Law/ IPR, thus, can attract persecution in a court of law, making it

imperative for every member of the corporate world to learn its technical and critical components. In an effort to create awareness and knowledge sharing regarding these issues, The Centre for Intellectual Property Rights, Research and Advocacy (CIPRA) was established in 1998 by The National Law School Of India University (NLSIU), Bangalore. CIPRA has developed the following website http://www.iprlawindia.org/iprlaw/ with the support of NISSAT (National Information System for Science and Technology). It provides comprehensive coverage of Indian intellectual property resources.

India needs to set up exclusive judicial courts to deal with intellectual property rights (IPR) issues, which are on the rise, according to the noted legal expert and patents judge, Mr Michael Fysh, who states that India has moved from the developing to a developed country status as far as IPR is concerned. Mr Fysh advocates that these courts should have at least two assigned judges who have experience in practice of IPR work and also a science degree. The IP Court should not be a tribunal as in the case of environment, consumer or labour courts because of the nature of the issues involved. The life of a patent is technological risks, involved in this process of transformation, too, will need to be well addressed. Ignorance and non-compliance of Cyber Law/ IPR, thus, can attract persecution in a court of law, making it imperative for every member of the corporate world to learn its technical and critical components. In an effort to create awareness and knowledge sharing regarding these issues, The Centre for Intellectual Property Rights, Research and Advocacy (CIPRA) was established in 1998 by The National Law School Of India University (NLSIU), Bangalore. CIPRA has developed the following website http://www.iprlawindia.org/iprlaw/ with the support of NISSAT (National Information System for Science and Technology). It provides comprehensive coverage of Indian intellectual property resources.

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around 14 years and that of trademarks and designs is 15 in the Indian context, and therefore protracted litigation does not help, as told by Mr. Fysh, currently judge, patents county court in London, to Business Line magazine to be assisted by independent assessors, qualified in science, the IP courts could deal with patents, designs, trademarks, copyrights and breach of confidential information among other issues, he said. The British legal expert, who is the last of his countrymen to be a member of the Bar in India, represents foreign and Indian companies in cases in the country and the sub- continent through his juniors. Mr. Fysh expressed skepticism about the efficacy of police courts, which seek to control copyright, piracy and counterfeit cases. They can be a deterrent, but not very effective, since the police are not IP lawyers, he argued. The police, customs and the judiciary should play a proactive role in curbing the menace of piracy that is threatening to kill the culture industry in the country. India needed an IP court like the ones in Thailand, Korea, Germany, UK or the US according to former Deputy Director-General, World Intellectual Property Organisation (WIPO). Source: Technology,

Information, Forecasting Assessment Council (TIFAC), Department of Science and Technology, Government of India. In this context Tables 1 & 2 are relevant.

Country	Agency	Cost	Uses allowed
Denmark	Danish Data Archive	No cost For non-commercial use.	May not be redistributed. May only be used for stated purpose after which data must be returned/destroyed.
Ireland	Ordnance Survey Ireland	Varies with intended use	Uses are licensed according to categories of activities (e.g., for architects, solicitors, Internet, etc.)
New Zealand	Crown Research Institutes	Recovery of direct costs is allowed	Open, except where use is not to the benefit of New Zealand
UK	Ordinance Survey	Cost recovery is allowed	Uses are licensed according to categories of activities
USA	United States Geological Survey	Reproduction and handling	Unlimited

Table 1: World wide data use or ownership policies of mapping or data agencies

Patenting Geographic Information Systems, Software/Products and Services

While it is indeed a valuable proposition that intellectual property rights need to be protected for a persons/ companys business strategies, future growth and service to the humanity, it is equally necessary that concerned team of groups or individuals are aware of such IPR issues. Table 3 below shows typical ideas/ products/ services/ inventions that are being patented recently in USA/Japan/China. For details please browse through the Internet. Only sample listing is shown, for authenticity and details of patents, one needs to go into details of each patent). Glancing through such patenting table throws light on each of us who are involved in the development/ deployment/implementation of such technology/ innovative idea that more awareness needs to be created among us on how to proceed on each and every stages to patent an invention or development of algorithm and value-added services/ products related to GIS and allied spatial technologies like remote sensing, GPS, digital image processing and networking. It becomes even more critical in a network sharing work environment (say futuristic NSDI infrastructure) whereby every individual efforts needs to be rewarded/rights are to be protected and any such negligence is challengeable in court of law.

Table 2: Analysis on comparison of basic features of different mechanisms for protecting intellectual property

S.No	Mechanism	Applicable to data per se	Database	Software	Geographic coverage	Comments
A	Copyright	No	Yes	Yes	Respected across jurisdictions.	Only protects form of expression, not ideas or data.
B	Patent	No	No	Yes	Requires application in each country.	Not all countries allow patents on
C	Database protection	Yes	Yes	No	Only vailable in certain countries	Concepts of fair use remain to be established.
D	Written License	Yes	Yes	Yes	Terms used in licenses vary with country (for ex., workservice")	If well written, provides perhaps the least risk of misunderstanding. Especially useful when dealing with agreements among diverse organizations.
E	Shrink-Wrap	Yes	Yes	Yes	for hire" vs. "contract of/for uncertain	Validity of such licenses is still bein tested in courts.
F	Trademark	No	No	No	Requires application in each country.	Used only for names and logos.
G	Trade secret	Yes	Yes	Yes	Laws protecting secretsvary greatly	Requires that deliberate efforts be made to keep information or product secret.

Table 3. Examples of recent US patents related to Geographic Information Systems.

The assignee is the individual or entity to whom ownership of the patent was assigned at the time of patent issue, typically the business that employed the inventor(s).

Patent No	Title	Assignee
6411899	Position based personal digital assistant	Trimble Navigation
6408107	Rapid convolution based large deformation image matching via landmark and volume imagery	(information not available on USPTO database)
6404920	System for generalising objects and features in an image	(information not available on USPTO database)
6389356	Geographic information system	Matsushita Electric Industrial Co
6353832	Selectivity estimation in spatial databases	Lucent Technologies
6337693	Vector-based geographic data	Autodesk
6321158	Integrated routing/mapping information	Delorme Publishing Company
6308177	System and method for use and storage of geographic data on physical media	(information not available on USPTO database)
6307573	Graphic-information flow method and system for visually analysing patterns and relationships	(information not available on USPTO database)
6282362	Geographical position/image digital recording and display system	Trimble Navigation Limited
6262741	Tiling of object-based geographic information system (GIS)	PRC Public Sector
6247019	Object-based geographic information system (GIS)	PRC Public Sector
6240424	Method and system for similarity-based image classification	NBC USA
6240360	Computer system for identifying local resources	Multipmap.com
6229546	Rapid terrain model generation with 3-D object features and user customisation interface	Geosoftware
6216130	Geographic-based information technology management system	InGeo Acquisitions
6115672	Method for measuring and quantifying amounts of carbon from certain greenhouse gases sequestered in and by grassy and herbaceous plants above and below the soil surface	Environmentally Correct Concepts
6107961	Map display system	Kokusai Denshin Denwa, Japan/USA

Conclusion

While authors appreciate the efforts taken by the government of India in creating awareness on IPR and related issues , especially by CSIR, TIFAC, DST etc, it is yet to draw comprehensive IPR policy covering the entire business processes and value-added services. In fact our attempt is one of the first of its kind to create such awareness within the paradigm of geo-spatial solutions and services industry, especially GIS and related systems development. The paradigm of intellectual property rights and its role in development of GIS systems/ applications/value-added services are of immense value with reference to the growing GIS industry segment coupled with expected availability of high to very-high resolution satellite data products through traditional means or over Internet. Indian geo-entrepreneurs are yet to make headway into this arena.

A set of guidelines for managing spatial information related IPR and other interesting details could be seen from the CAS web-site and other listed web references.

Privacy Issues in Geographic Information Technologies

Introduction

The concept of privacy varies widely between societies, across time and even between individuals. Therefore, providing a succinct definition of privacy is difficult because one person′s concept of what constitutes privacy intrusion can be very different from another′s. An extensive survey of personal privacy (Rotenberg and Laurant 2004) was carried out by Privacy International as part of the Global Internet Liberty Campaign. The original report is now revised and extended on a yearly basis and identifies four broad privacy categories:

Information privacy:

> protection of data containing personally-identifiable information; examples of personal data include medical records and bank statements.

Bodily privacy:

> protection of people from physical invasion; examples of bodily invasion include drug tests, cavity searches and genetic testing.

Privacy of communications:

> protection of all forms of communication from interception; examples of interception include monitoring telephone, email and written correspondence.

Territorial privacy:

> protection of domestic, work and public space from intrusion; examples of intrusion include search warrants, video surveillance and identity checks.

Gavison (1980) took an alternative approach and defined privacy in terms of three commonly asserted moral rights connected with privacy:

Solitude:

> the right to control access to a personal space; examples include undisturbed reading of a book in a park or enjoying a meal with family and friends at home.

Secrecy:

> the right to control the collection and onward distribution of sensitive personal information; example types of information include medical records, family photos and private communications.

Anonymity:

> the right to remain anonymous and unnoticed in social interaction; examples include shopping for goods and services without identification and the ability to speak freely with anonymity.

In many traditional social structures, individuals experienced relatively little solitude, secrecy or anonymity; gossip could spread intimate personal details and actions of other members of the community quickly. Such information was rarely spread outside a community since the method of communication was often by word-of-mouth and the information transmitted would generally have little relevance to remote communities, except where it concerned a famous or wealthy individual. As most events were committed to memory rather than written down, past events were tempered by time since recent actions of an individual allowed the community to subconsciously re-evaluate an individual′s previous behaviour.

At the dawn of the industrial era, large metropolitan areas developed and people gathered together in much greater numbers. This enabled the general populous to enjoy much greater levels of anonymity than was possible in a small and relatively closed community. During the same period the reading and writing skills of the population improved as better education became available to the masses. Writing enabled individuals to record and distribute an immutable record of current events; this, together with the development of the printing press and instantaneous photography, enabled invasion of the secrecy and solitude of an individual on a much larger scale than was previously possible.

Developments in science and technology over the last century continue to provide individuals, companies and governments with new and more invasive ways to intrude on the privacy of individuals and communities. Since the latter decades of the 20th century, computer systems have developed their capacity to collect, analyse and distribute sensitive information at an exponential rate. This, together with advances in medicine, transportation, finance and communication have resulted in the recording and preserving of many more private facts.

Globalisation has also accelerated the analysis and distribution of private data through the development of high-speed computer networks and the growing number of interoperability standards. Examples include the Internet Protocol, facilitating ubiquitous network connectivity, and standardised data storage formats and meta-formats such as XML.

There are many reasons for recording and distributing personal information. Most governments, while wildly varying in political constitution, now demand some personal information from citizens; examples include earnings, family make-up, religion and qualifications. The stated goal of data gathering is that of collective good for society; in many cases the benefit is clear, for example, the regulation of medical practitioners, but in some cases the societal benefits are less obvious.

Commercial organisations are primarily concerned with profit, yet companies are often much more invasive than their governmental counterparts. Traditionally, marketing,

advertising or brand loyalty have been suggested as the major motivation, but more recently price discrimination–the act of charging individuals a personalised price based on the amount they are prepared to pay–has been suggested as a strong motivating factor.

Discriminatory pricing works best in markets with large, fixed, up-front costs and low marginal expenses. With the centralisation of services and reduced cost of communication and transportation, more industries fit this model. Price discrimination is not a new phenomenon: it was used extensively throughout the early development of the railways in the US and Britain until a customer backlash introduced extensive regulation. Traditionally its use has been limited by the lack of technology to perform detailed customer profiling, however recent developments in computer systems make such techniques relatively simple and cost effective.

Recent price discrimination examples include flights, computers and even DVDs. The region coding scheme on DVDs was (in part) motivated by the desire to enforce a price differential on discs sold in different areas of the globe. In September 2000, Amazon experimented with price discrimination on for customers buying otherwise identical DVDs; this practise was quickly discovered by Internet users and was widely reported in the press. The situation had the Amazon community split–some thought the practise was fair, others abhorred it.

Specific GIS privacy issues

The development of the Geographic Information Systems (GISs) mirrors the technological development of computers and the globalisation of government and industry. Traditional GISs ran on mainframe computers with relatively little computational power and data were often entered manually by the users of the system. Desktop GISs widened the market and, with the development of computer networks and cheap, removable media, increased the ability of individuals to copy and distribute geographic information. Recent developments in GISs have seen further growth in distributed processing and real-time data sharing over the Internet.

The types of data stored in a GIS are not restricted to solely topological facts; rather, the aim of many GISs is to spatially index and cross-reference multiple datasets containing a wide variety of information, and much of this data may well be of a personal and private nature. Therefore, the potential for privacy invasion of spatially-indexed personal data can be at least as problematic as a generic computer database.

Due to the expense of mainframe computer systems, early GISs were predominantly used by governments and large corporations. Typical government uses include tax assessment, zoning and planning, environmental impact analysis and maintenance of transportation and utilities. Businesses with a direct involvement in the exploitation of natural resources have an obvious need for recording and processing spatially-indexed data, yet the spatial indexing of personal data has many other uses for commercial enterprise.

Geodemographic software systems are a particular type of GIS used to categorise individuals living within a particular geographical region with a common set of socio-economic attributes. Such databases are popular with a wide variety of businesses. For example, mass marketeers use demographic data to direct advertisements to specific regions and thereby reduce postage costs on sending adverts to areas deemed unlikely to be responsive to a particular product. Other businesses use location data to determine the best location for retail outlets or to offer a potential customer a personalised price for house and motor insurance.

Traditionally, companies producing geodemographic software believed the accuracy of the system depended on the size of the region associated with a particular demographic, the quality and variety of the data used to generate the demographic for each area, and the number of possible socio-economic attributes. Therefore, by reducing the size of the geographical region, a geodemographic system should select a more socially homogeneous group, and this, together with more detailed and accurate input data about the group, combined with a greater number of possible attributes, should produce more accurate geodemographics. There are, of course, limits to the accuracy of such an approach; nevertheless the continued existence and popularity of geodemographic systems in the business community demonstrates their utility.

Recent technical innovations such as GPS and mobile telephone location systems show the potential for dynamic geodemographics. With this technology, geodemographic analysts can use the set of locations an individual visits during the day rather than just their permanent home address. Proponents of geodemographics anticipated that this set of data will provide better insights into the socio-economic groups of individuals. This concept can, of course, be extended to allow fully fledged location-based services where advertisements or products are offered to potential customers based on their current geographic location.

Geodemographic software encourages the practise of ″redlining", where business avoid offering services such as mortgages or insurance to geographic areas considered to be a poor economic risk. Such practises represent a form of discrimination, but may also be interpreted as form of collective or territorial privacy violation, since personal data is gathered from a community and used to generate a, perhaps unfair, or at least generalised viewpoint of the population.

Indigenous people have also expressed concerns over the use of GISs. Worries about GISs stem partly from a cultural desire for collective territorial privacy, where certain regions are considered sacred and private and as such should not be visible to outsiders. GISs can be used to determine regions rich in natural resources and therefore indigenous populations are concerned that recording such information may lead to pressure from governments and commerce for exploitation. The data does not even have to be collected locally, and this reduces the ability of the local population to control the access to, and dissemination of, information about their land. Satellite imaging systems integrated with GISs can be deployed remotely by governments and commercial organisations to intrude on territory without the consent of the local population.

GISs raise both information privacy and territorial privacy concerns. Protecting the set of movement data from a specific individual is a form of information privacy, whereas protecting the information concerning personal or collectively private spaces is an instance of territorial privacy.

Future directions of computing and GISs

The price of computers continues to fall dramatically, following the downward price trend which started almost as soon as computers entered mass production. Astoundingly, as the price of computing has dropped, the performance and portability of computers has increased immensely. Most people in richer nations no longer own just one computer, but a dozen. If the price, performance and portability trend continues for much longer, the average consumer will soon be able to afford a hundred or a thousand small and powerful

computational devices. Many of today′s computers operate independently, however as the deployment of wireless technologies takes hold, devices will soon start to inter-operate.

Weiser noticed these trends over ten years ago and used them to provide some predictions about computing in the 21st century. He coined the term ubiquitous computing to describe a world in which computers ″weave themselves into the fabric of everyday life until they are indistinguishable from it" and claimed that ″the most profound technologies are those that disappear." He noted that other technologies have done this before, and envisioned computing becoming sufficiently embedded into our world that users would often interact with computers at a subconscious level, much like we do today with the written word on signs, billboards, books and magazines; ″in essence...only when things disappear in this way are we freed to use them without thinking and so to focus beyond them on new goals."

Most individuals are incapable and unwilling to manage a thousand devices in a similar fashion to the control and configuration required for a typical home PC today. Therefore, if ownership of a thousand computers is going to be productive, methods will be needed to automate the vast majority of the tasks these new devices are designed to perform. At the same time, techniques for reducing the cognitive load placed on users through improvements in human-computer interaction will be required.

Context-aware computing(Schilit et al. 1994) or sentient computing (Hopper 2000) augments computers with sensors and actuators in order to achieve a better understanding of, and interaction with, the physical environment. Such systems collect sensor data to build a model of the environment or world model (Adly et al. 1997). Human-computer interaction can then be improved, since individuals can use their five senses to interact with the computer within their real environment, rather than through a screen, mouse and keyboard. A computer system can also make use of the rich and diverse set of sensory inputs to trigger actuators and therefore automate tasks on our behalf. Effective context-aware systems should be easier to use than the traditional computing infrastructure commonplace today and it will therefore enable the average individual to make use of a much larger number of computers than would otherwise be possible. In many respects context-aware computing provides a way to realise the goal of ubiquitous computing.

Researchers in the field of ubiquitous computing have struggled to provide a precise definition of context, yet, from a privacy perspective, it is important to consider what types of information may be required to enable the successful operation of a context-aware system. López de Ipiña describes some of the common attributes, which include identity, location, time, features of the natural environment, such as temperature, light level, air quality etc., physiology, activity, social interaction and nearby resources (López de Ipiña 2003). Dey and Abowd claim there exist four primary context types which characterise any particular situation of an individual or object (Dey and Abowd 2000):

Identity:

the identity of relevant entities.

Location:

the geographical position of relevant entities.

Activity:

the activity or activities being performed.

Time:

the time period at which the entities perform the activity.

All other types of context information are declared secondary because they require association with one or more pieces of primary context to be meaningful. For example, a phone number, address or date of birth is usually associated with an identity; similarly temperature information is only useful when combined with a location, time and possibly activity. It is usual for secondary context to require more than one piece of primary context in order to identify unambiguously a single piece of information; in database parlance, the primary contexts must be combined to form a composite key.

A large amount of research in the field of ubiquitous computing has focused on enabling location-awareness and location-based services. In many cases the scale of these research projects is small in comparison to both the geographical size and data richness of commercial GISs. However integrating serious GIS systems will become a necessary component of ubiquitous computing systems as the technology is transferred from research groups and into commercial deployment.

Providing computers with knowledge of the context of users means that computers will gather, collate and distribute much more personal information about individuals than they do today. Such personal information is often considered private. Therefore, there appears to be a fundamental conflict between personal and collective privacy and the needs of context-aware computing. The next section outlines some possible methods which can redress the privacy imbalance between the deployment and use of GISs. Particular focus is given to future issues which arise when real-time location information of individuals becomes available for use by GISs and ubiquitous computing systems.

Protecting privacy

Lessig (1999) describes the four basic constraints which regulate the behaviour of individuals: architecture, social customs, market and law. Each constraint poses a distinct but interdependent cost on the individual. Constraints can be complementary or opposing, yet all can ultimately be governed by the rule of law. Architecture and the market regulate behaviour before an action can take place: a locked door prevents unwanted entry and the cost of cigarettes deters consumption. Social customs and law regulate behaviour after the event: diners may scorn if you smoke while eating and the police may arrest you for trespassing on private property. Most individuals feel the threat of social customs or law before the action even though social customs or law cannot actually prevent the act, unlike architecture or market forces.

Law is able to directly regulate behaviour through statute, and indirectly by regulating architecture, social customs and the market; examples of indirect regulation include building codes, sex education in schools and cigarette taxation. Such indirect regulation does raise questions of transparency, particularly in the regulation of architecture. For example Lessig describes how Robert Moses commissioned the bridges constructed on Long Island to prevent the passage of buses–the primary transportation of African Americans–preventing the progress of public transport to the beaches.

There are occasions when breaking a regulation may be morally justifiable, for example, speeding to hospital with the seriously ill; law and social customs are good at adapting in this situation, but architecture and the market are not; for example, a vehicle′s speed

limiter always limits. Therefore architectural and market forces are arguably more powerful but less adaptable regulators.

This distinction has important implications for the regulation of privacy. Law alone is not sufficient as it is not the most efficient method to prevent unwanted intrusion into the private lives of individuals because: firstly, privacy is very subjective–what is acceptable to one person is unacceptable to another; and secondly, post-action retribution through law may not be able to provide any good remedy— "the cat may already be out of the bag." This does not mean law-makers provide no aid in protecting privacy; quite the opposite is true–law has a crucial role to play in controlling architecture, market forces and social customs to foster privacy.

Legal instruments

Almost all countries now recognise privacy as a fundamental right and have attempted to codify privacy in law. The first known piece of privacy legislation was the 1361 Justices of the Peace Act (England), which legislated for the arrest of eavesdroppers and stalkers. In 1890 Warren and Brandeis argued that citizens should have the right to prevent disclosure of personal information as a separate right to that of copyright law or of slander or libel (Warren and Brandeis 1890). More recently, the 1948 Universal Declaration of Human Rights (United Nations 1948, Article 12) states everyone has a right to privacy at home, with family and in correspondence. This declaration was reaffirmed in The European Convention on Human Rights (Council of Europe 1950, Article 8) and the International Covenant on Civil and Political Rights (United Nations 1966, Article 17).

Many other more recent pieces of legislation aim to protect citizens privacy; some modern constitutions even go as far as expressing the specific rights of access and control of personal information. Lessig argues that we should go further than just protection and recognise (certain pieces of) information about individuals as "real property" in order to provide individuals with the ability to control the dissemination of their data.

The legal protection for personal privacy differs markedly across the globe. Some countries, such as Europe, Australia, New Zealand and Canada, have a comprehensive regulatory model. For example, the European Union regulates the collection of and access to all personally-identifiable information. The 1995 Data Protection Directive (European Union 1995) harmonised data protection law across all member states and embodies Westin's principles of privacy (Westin 1970), namely openness and transparency, reasonable security, accountability, collection and limitation, data quality, usage limitation and individual participation.

Accountability, openness and transparency is ensured through the supervisory authority which has the power to investigate, intervene, temporarily or permanently stop processing and ban the use of, or order the erasure of data. Further, the supervisory authority has the power to initiate legal proceedings in cases where the directive has been violated. All companies and individuals collecting and processing personal data must notify the supervisory authority of their intention to process data.

The directive demands that personally identifiable data are, firstly, collected for explicit and legitimate purposes, and not further processed in a way incompatible with the original purposes; secondly, accurate and kept up-to-date– inaccurate data must be either erased or rectified; thirdly, relevant and not excessive with respect to the purpose of collection; and

finally, only stored for as long as is necessary for the purposes for which the data was collected.

The directive also requires explicit consent or a demonstration of necessity of processing– this can include a legal or contractual requirement where the data subject is a party, or for the protection of vital interests of the data subject, for example, emergency recovery of medical records in the event of an accident. Furthermore, data subjects are also entitled to access their personally identifiable information ″without constraint, at reasonable intervals and without excessive delay or expense.”

The comprehensive model proposes an architecture, backed by legal punishment, to regulate and control data processing of personally identifiable information. It is worth noting that, at least in the case of the European model, regulation only applies to personally identifiable information, and as such does not necessarily provide protection against territorial privacy violations. In addition, the directive does not require consumer choice; as Langheinrich notes (Langheinrich 2001), notice and consent are of little good if consumers have no choice.

Other countries take a broadly sectorial approach to privacy legislation by enacting statues when specific privacy problems arise. Specific regulation often lags behind current developments in technology, and can leave vast areas of commerce insufficiently regulated. The United States, for example, does not have a comprehensive regulatory model, and the US constitution does not specifically mention privacy at all, although the Supreme Court has interpreted certain passages in the Bill of Rights to protect a person from government surveillance when they have a ″reasonable expectation of privacy” and has recognised a right to anonymity in the context of free speech. In addition some states have incorporated a more general right to privacy into their own constitutions.

The US Federal Privacy Act of 1974 attempted to introduce some of Westin′s principles to protect the privacy of citizens from invasion by the government; however, the act did not limit or control the behaviour of private industry. The effectiveness of the legislation has been limited by poor enforcement and a broad interpretation of ″routine use” which permits data collected for one purpose to be reused for other similar purposes.

In 1977 the Supreme Court ruled that individuals do not have constitutional protection for private data once it has been transferred to third parties. To date, the federal government has not provided comprehensive legislation to regulate private industrial use of personal data. Instead it has enacted a series of laws to cover specific cases, with the result that, for example, video rental records are better protected than drug purchases.

Various industries have attempted self-regulation through codes of practice, however many of these bodies suffer from a lack of effective enforcement and therefore have less impact than primary legislation; furthermore, industry-wide consensus does not necessarily result in good consumer privacy, although the threat of government intervention for poorly performing industry codes of practise may have some positive effect.

Architecture

New technologies do not necessarily decrease the level of privacy experienced by its users–some technologies can be used to increase the level of privacy experienced by an individual or group. Technology is not privacy neutral: the details of the design and implementation, or architecture, of a computer system can have a profound effect on

privacy experienced by its users. The previous section described how different countries have regulated the design and use of computer systems in processing personal information. This section describes some possible design strategies which can be used to minimise the privacy problems presented by GISs.

The first question to ask is: should the data be collected at all? There are numerous occasions when data collected for one purpose are subsequently used for many others. Such ″mission creep" is explicitly forbidden in some territories, such as the European Union, where data collected for one purpose cannot be used for another. Unfortunately, there remains a strong desire to reuse information already collected and processed, and this motivates governments to pass exemptions or reinterpret data protection legislation. The same situation encourages companies to write overly broad usage requirements for the collected data, so that every conceivable data processing need is covered.

There are two common techniques which can be employed to reduce the privacy impact of storing personal data; both of these approaches are suitable for GISs. Firstly, access control can be used to restrict the flow of data to specific individuals or organisations; however configuring access control is difficult, and assessing the trustworthiness of the entities given access can also be problematic, especially in a large system. Secondly, anonymisation can be used to remove any personal identifiers from the dataset, thereby mitigating many information privacy concerns; however, difficulty arises in determining whether the dataset has been sufficiently anonymised and whether it is of any use after anonymisation. An overview of these two methods of privacy protection will now be considered in the next two sections.

Access control

Traditional database systems store relatively static information on a server which is usually run and managed by the company, government or individual who wishes to process the data. Therefore the data subject, be that an individual or a community, loses the ability to directly control the use of that information. The comprehensive model, and in particular the one promoted by the European Union, attempts to redress this imbalance by giving data subjects the ability to access and control the onward distribution of their data, even when it is no longer stored on a computer under their control.

Allowing data subjects to determine a policy which controls access to, and onward distribution of, their personal data is an example of multilateral security, where each data subject can each impose a set of their own, independent access controls on their portion of the overall dataset. Distributed GISs (see Chapter 5) make distribution of an access control policy harder, since the physical storage location and usage of personal data is distributed; there is no longer a single entity an individual can approach in order to access and correct personal data. Distributed systems also make the specification of policy itself inherently more difficult. Distributed systems are going to become increasingly commonplace in computing, and therefore this is a problem which must be tackled, yet the information privacy issues presented by highly distributed systems have received relatively little interest. One example use of multilateral security to control personal data in a distributed system is the British Medical Association model for electronic patient records(Anderson 2001); individual components of a patient record can be compartmentalised to restrict access to particularly sensitive information, such as HIV test results, from the majority of medical staff.

The specification of access control policies is likely to get increasingly difficult as the number of computers increase and data is distributed over increasingly heterogeneous computer systems and networks. The reduction in cost of computers and rise in the number of broadband Internet connections does, however, present a new possibility. In the near future, data subjects may be able to afford a computer and network connection which is powerful enough to store and distribute all their own personal data. Third-parties which request access to personal information may be forced to request access to the data as and when required. This, highly distributed, architecture, places the data subject back in control of their personal information. Corporations and governments may resist such an architecture however, since: firstly, the current relative speed differential between local and network access to data makes a centralised solution more efficient for the foreseeable future; secondly, distributed systems are harder to build and placing users in control of data hosting may make such system less reliable; and, finally, data subjects may take more interest in the manner in which their personal information is used and therefore limit its use in a more rigorous manner. Therefore primary legislation may be required to force governments and companies to offer this architectural option to their citizens and customers.

Context-aware computing anticipates an era when computing systems will need to gather, collate and distribute much greater volumes of information in order to function effectively. In particular, continuous streams of location data from a variety of sensor networks, such as GPS and mobile telephone location systems, will be used by computers to automate tasks and reduce the level of concentration required to interact with a computer system. In this environment, spatial indexing of data will be a crucial component, since location data is one of the four primary types of context, and will therefore be used to index lots of other datasets.

Protecting privacy for individuals who release a continuous stream of location events is much more challenging problem than protecting relatively static location data. Combining a detailed GIS containing static information together with a stream of location information of sub-metre accuracy can reveal a wealth of personal facts concerning the individual being tracked, including, for example, the clinics visited in a hospital or the genre of books borrowed from the local library. Uncontrolled access to multiple streams of location data from multiple individuals reveals details of the social and business connections which exist in a particular community. The remainder of the section explores some possible computer architectures which can be used to control the release of personal information whilst simultaneously permitting location-based applications to function.

The IETF GeoPriv Working Group define a location services architecture designed to protect location privacy of individuals who make use of location- based services. The requirements draft (Cuellar et al. 2004) defines four, logically distinct, service components, which are shown in Figure 2, as well as two data objects: location data owners specify privacy rule objects to describe the access control to be applied to every location object, which represents a location event associated with a particular identity.

The location generator service object determines the location of the entity being tracked and constructs a location object to describe the current location. The location generator then publishes the location object to one or more location servers which receive location objects from, possibly multiple, location generators; the location server may receive subscriptions for location information from location recipients.

The rule holder service stores privacy rules on behalf of the rule maker. The rule maker is usually the owner of both the location device and the location information; there are exceptions however; for example parents may be rule makers of their children′s location information and employees may be rule makers for corporate mobile telephones. The location server applies any privacy rules it learns from the rule holder to the location objects it receives and then notifies the location recipient of the location object as necessary.

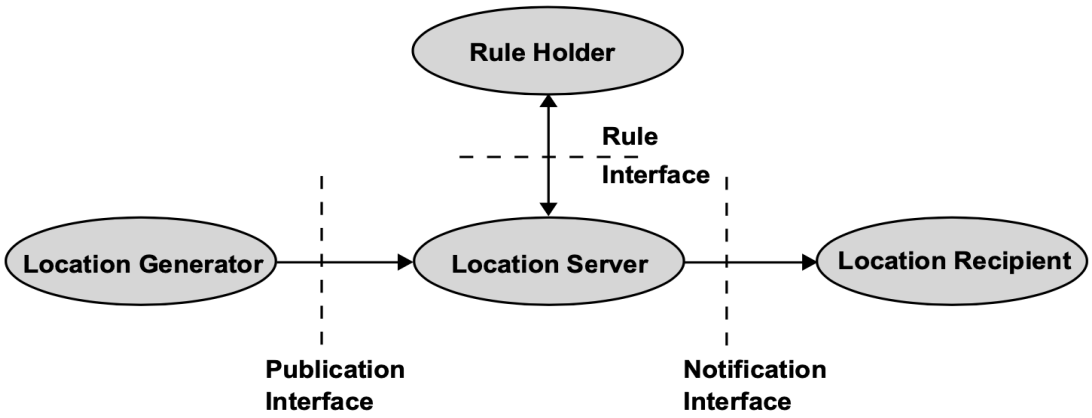


Fig. 2 The four primary GeoPriv components.

The rule maker may amend any of the parameters in the location object to increase the privacy of the target; common adjustments include: anonymising the target identifier by using pseudonyms (see next section); reducing the spatial resolution, for example converting 15 Bridge Street, Cambridge, England to City Centre, Cambridge, England; and reducing the temporal resolution of the data.

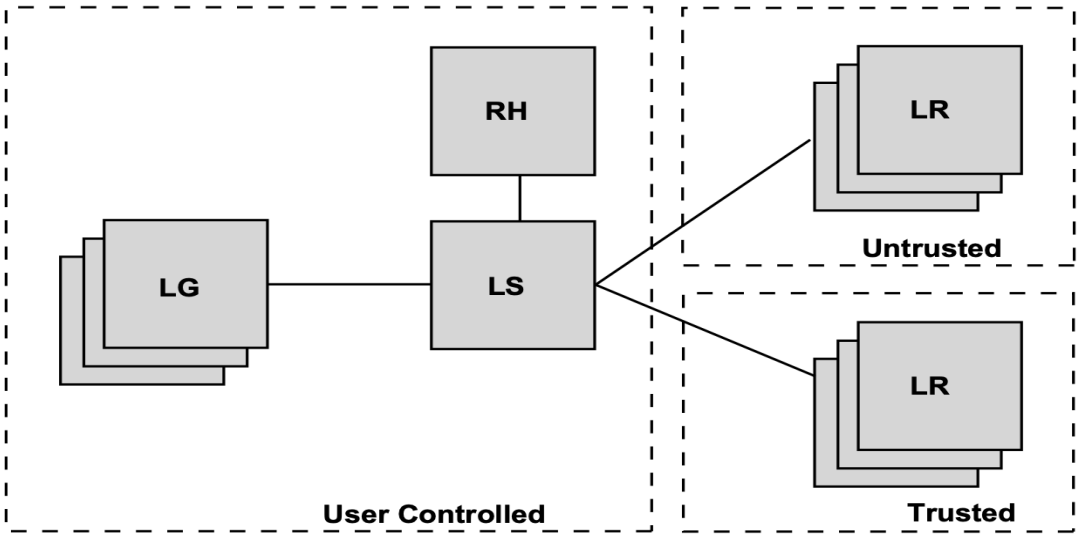


Fig. 3 User-controlled model.

The location application can be stream-based and therefore request from the location server all events concerning a specific set of individuals, or event-based, and request from the location server information about any user located within a particular spatial region. An example stream-based application might locate a particular user on map together with the current location of local amenities and perhaps the location of friends; an event-based application might notify a user if they pass an historic building of interest or offer a reminder when they next meet up with a particular companion.

The ownership of, and trust placed in, each of these services can affect the level of location privacy offered by the architecture to the users of the system. User ownership of all the components in a location architecture reduces the need to trust third-parties and implement (potentially complex) privacy restrictions. User ownership of all components of the location architecture is not always possible, or indeed desirable; these issues are outlined next with the introduction of four possible architectures in which service components are owned and controlled by either: the data subject, a trusted third-party, or an untrusted third- party.

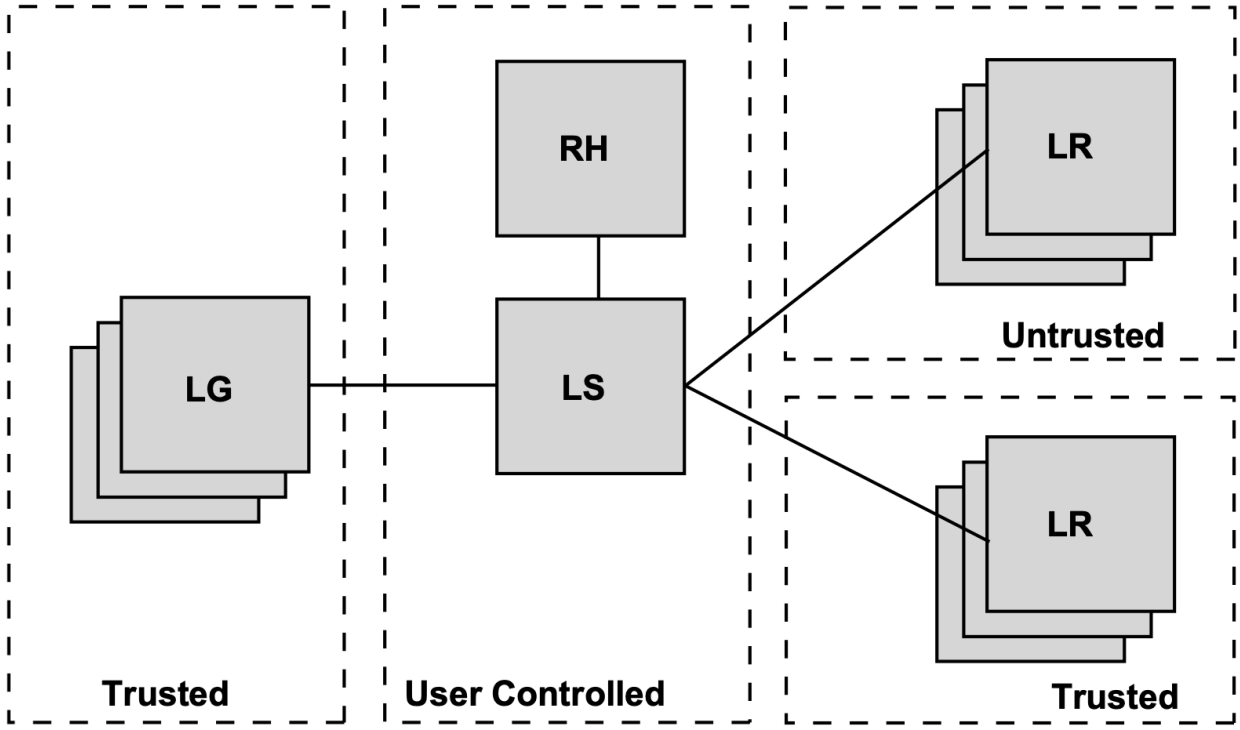


Fig. 4 User-mediated model.

The user-controlled model is depicted in Figure 4. In this model the location generators are location systems which can calculate their location without revealing their presence to any infrastructure controlled by third-parties. Therefore, all location data initially resides solely with the data subject; this places the user in direct control of any release of location information. In addition the location server and rule holder are under the direct control of the user, and therefore the user can restrict access to location information to authenticated applications or (after anonymisation) to untrusted applications. In the case when location applications are also under user control, no trust is placed in third parties and therefore location privacy is assured if the software and hardware implementation is secure. Car

navigation software fed from a local GPS receiver is one example of a user-controlled location service.

The user-controlled model is very suitable for personal location applications–the user is in direct control and, provided the hardware and software is well designed, nobody other than the user can possibly determine any personal location information. However, this model has two major drawbacks: firstly, users can (via applications) locate themselves quickly and efficiently, but determining their context (e.g., other users or objects nearby) requires the application to know about, be trusted with, and contact every other user′s location server (an overhead a centralised location server is designed to prevent); and secondly, the model requires the user to carry around a device capable of deriving location information, storing the relevant GIS databases and executing applications. The device may need significant resources in order to store and process a lot of data.

The user-mediated model is depicted in Figure 4; in this model the user does not own the location generators, which may be controlled and managed by a central authority, but instead the user owns, and controls, only the rule holder and location server. The rule holder and location server could reside on a roaming device carried with the user, or remain on a home PC connected to the Internet. The optimal position of the location server and rule holder is dependant on the likely usage of the location information: a home PC is suited to location- aware applications used by people other than the owner of the location information (since its connectivity is likely to be better), whereas a PDA may be more convenient if location services are to be used by the roaming user.

This model does not support shared location information efficiently since a user′s context cannot be determined easily. The model does have the advantage of enabling the user to reduce the amount of resources present on the device which must be transported with him; for example if a visual tracking system is used and application actuators are placed in the environment, the user does not have to carry any device at all.

The third-party model is depicted in Figure 4. All the main components of the architecture are controlled by one or more trusted entities on behalf of the user. The location server and rule holder may be run by a collective of friends and family, an independent service provider (e.g., mobile phone operator) or by an employer. In this model applications can be built to use contextual information based on location information from other users of the location server.

In this model the user must trust the service provider to correctly configure the required software and hardware for the rule holder and location server. At the most fundamental level the user therefore relies on contract or privacy laws in order to ensure the correct level of location privacy is provided. Relying on legal protection ultimately requires a reliance on the government; in other words, if the government grant themselves (and possibly others) exemption from privacy legislation then the user may have to accept invasions in location privacy.

In some situations a hybrid model is a likely outcome where different location technologies are combined in an iterative fashion to build a hierarchy of location servers; see Figure 13.5. For example, some mobile phone users will soon have handsets with built-in GPS and WiFi and in this case GPS and WiFi location services may act as location generators; the user can distribute the resulting location information via the data interface of the mobile phone either directly to their friends and family (by running a

location server and rule holder on the phone) or via their own user-controlled remote location server.

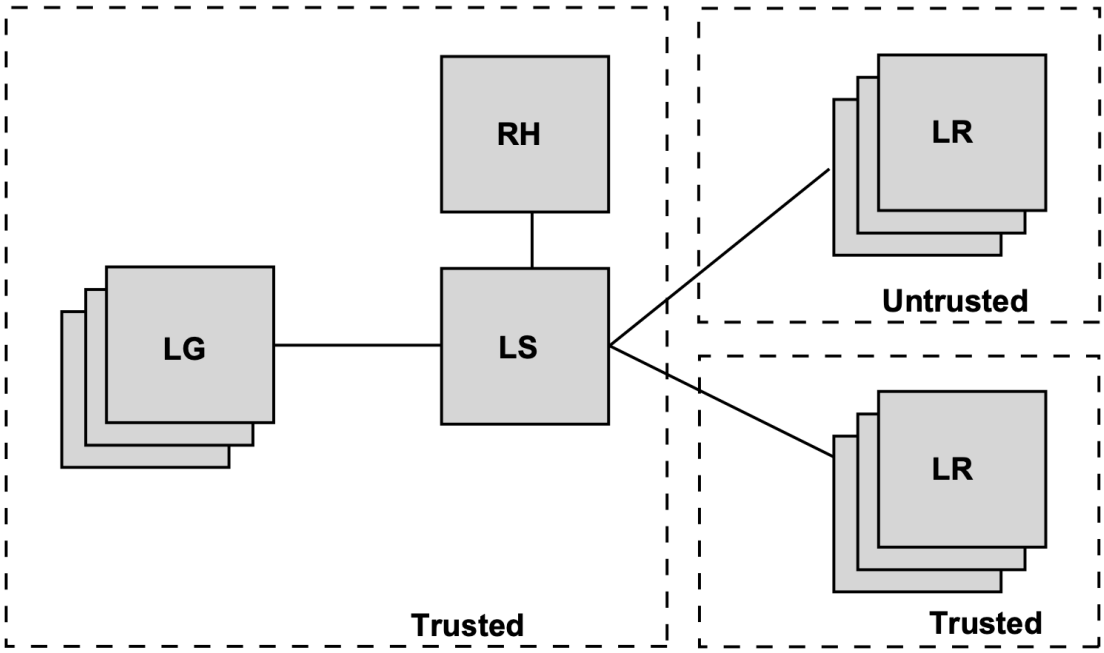


Fig. 5 Third Part mode

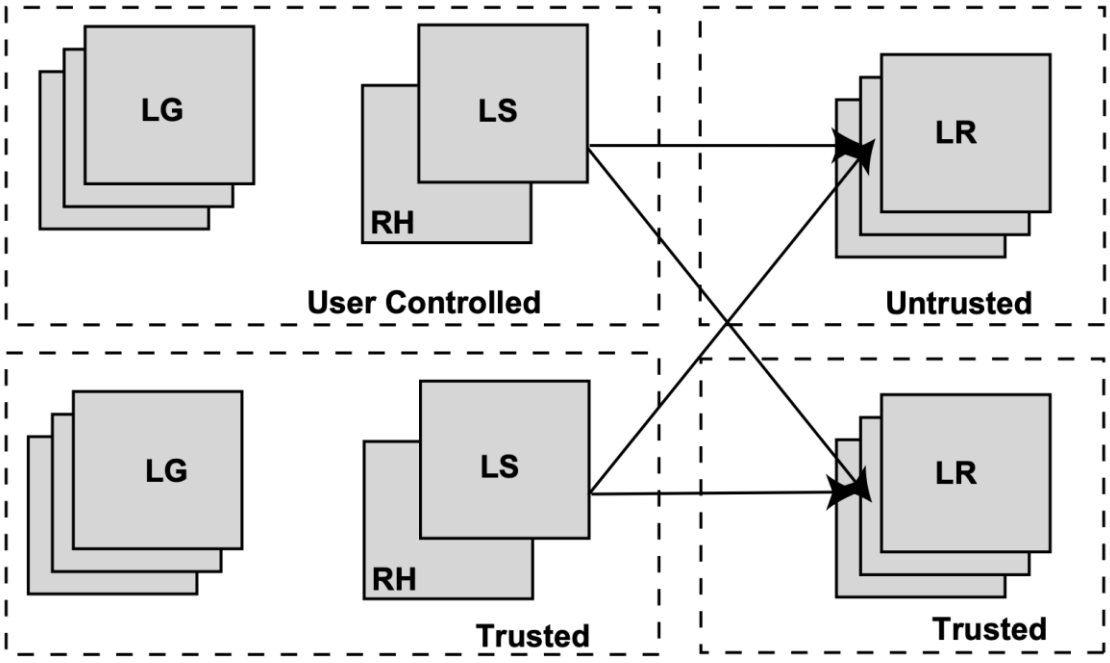


Fig. 6 Hybrid Model

Irrespective of the distribution of location information determined from the GPS and WiFi location generators, the mobile operator can still determine (less accurate) location information from the phone using GSM location techniques and feed this information into the mobile operator′s location server. The user may also have the ability to provide a subset of location information from the (more accurate) GPS and WiFi location generators either directly to the mobile operator or via their own user-controlled location server. In this model the distribution of location information can be viewed as a multilevel secure system (Anderson 2001) where location servers form a trust hierarchy and distribute location information adjusted by privacy primitives to applications or to other location servers with less security clearance.

Anonymisation

Anonymity is defined by the Oxford English Dictionary as ″the state of being anonymous" which in turn is described as ″nameless, having no name; of unknown name." Anonymity can be used in order to protect information privacy by ensuring any data released to an untrusted party cannot be associated with a real-world entity. Note that anonymisation techniques do not necessarily protect collective or territorial privacy since these datasets do not always identify individuals. Within the computer security community, Pfitzmann and Köhntopp promoted a more specific, quantitative, definition of anonymity:

″anonymity is the state of being not identifiable within a set of subjects, the anonymity set."

The anonymity set is associated with an action or role performed by the members of the set. For example, in anonymous communications the sender anonymity set is the set of people who could have written a message which was subsequently intercepted; similarly, the receiver anonymity set is the set of people who could have received a message intercepted by an attacker. Measuring anonymity with an anonymity set is useful because it provides a quantifiable metric for anonymity.

Traditionally the cardinality of the anonymity set has been used as a measure of anonymity; a user who is ″k-anonymous" or ″has k-anonymity" is one of at least k users within a specific anonymity set associated with a particular action. Recently, Serjantov and Danezis defined an information theoretic measure of anonymity (Serjantov and Danezis 2002): each member ai of the anonymity set A is assigned a probability equal to the (estimated) likelihood that member ai performed the anonymous action. Shannon′s entropy measure (Shannon 1948) can then be used to quantify the level of uncertainty or anonymity the members of the anonymity set achieve collectively with respect to their action.

A wide variety of organisations collect personal information from individuals in the form of a survey or census. Inference Control or Statistical Disclosure Control (Willenborg and de Waal 2001) is the discipline concerned with the modification of personal confidential data collected from individuals in order to prevent third-parties using the data (e.g., government departments, academic researchers and pharmaceutical companies) from correlating confidential information with specific individuals.

Traditionally data were provided to third-parties in the form of aggregated tables of values, but increasingly individual data values, or microdata, are used. Statistical disclosure occurs when data provided for statistical purposes is misused. It is often not

sufficient to just remove explicit identifiers, since implicit information may also be hidden in the dataset. For example, a sociologist investigating urban deprivation may notice data concerning an (anonymous) 40-50 year old vicar, knows there is only one such respondent in the geographic area and knows his or her identity; the sociologist can then misuse the data to disclose other potentially sensitive personal data associated with the poorly anonymised record.

If access control could be used to facilitate location privacy it is important to ask the question: why bother with anonymity? There are a combination of factors which make anonymity-based techniques more attractive than traditional access control methodologies. First, users may accept anonymised location-aware services but shy away from services which require concrete identity. Typical real-world examples include the use of cash as an anonymous payment method for sports betting and the acceptance of false details as the norm when visiting a sexual health clinic.

Second, configuration of access rights is a difficult task for a skilled computer scientist; the situation may be nearly impossible for an average user. Role-based access control (Sandhu et al. 2000) and well configured defaults may mitigate the worst privacy worries, but these solutions will only partially solve the problem. Data subjects in today′s GISs often cannot adequately control the initial and onward distribution of personal data. In the world of ubiquitous computing GISs become more wide-spread and simultaneously the datasets are augmented with large collections of dynamic location information; providing manageable access controls on this scale becomes even more intractable. Anonymity side-steps the configuration problem by denying an application access to any personally identifiable data, and therefore is more suited to ubiquitous computing applications than access control.

Third, if applications can be made to work with anonymous location sightings, then the applications themselves need not be trusted. Any reduction in the trusted computing base of a system increases our confidence in its correctness; in location- aware computing, removing applications from the trusted domain will increase our confidence in user privacy. Concerns about programmatic correctness alone (e.g., buffer overflow exploits) would justify this reduction in the trusted computing base since the vast majority of code will reside in the application layer. (Making applications untrusted means that an attacker cannot use, say, a buffer overflow exploit in a location-aware application to determine the location of a particular person).

Privacy worries extend beyond concerns about program correctness. Several mobile phone operators have already deployed systems which permit third-parties to connect to their networks and gain location information of users. Therefore trusted applications require trusted third-parties. This requires contractual agreements between mobile phone operators and third-party application providers. In addition, third-parties may have to adhere to data protection laws since they are handling personally identifiable information. This would not be the case, if anonymous location information were made available.

Whilst anonymisation is attractive from the perspective of the user, it can make writing location-aware applications harder. Some location-aware applications will function on anonymised location data, in other words, data with all direct identifiers removed. Uses of anonymised location sightings include service planning, (for example, how many users of bus route 12 are there on an average Monday morning in winter), environmental discovery and control of shared resources.

The main characteristic of a truly anonymous application is the one- directional flow of data from user to application; information flow in the other direction is difficult because the application does not know which user to communicate with. One approach is to broadcast reverse path messages to all users, but this technique will not scale to large anonymity sets. Applications which interact with users via devices which have an inherent user identity associated with them cannot provide an identifier for return messages without sacrificing privacy; for example a mobile telephone or home server cannot provide a telephone number or IP address because these are considered direct identifiers under many threat models. Therefore many interactive applications require an unlinkable pseudonym in order to communicate with the user.

Fine-grained location information of the type required for many location- aware services provides a very rich data set of user movement. Users often have one or more regions of space and time they predominantly occupy; such regions are called home locations. The term simple home location is used to refer to any home location which can be identified with a single location event (i.e., a single co-ordinate, containment or proximity measurement associated with a timestamp); conversely, a complex home location requires two or more location events to enable an attacker to identify an individual. Consider the following examples: the set of people sitting at a particular office desk for the majority of the working day; people found entering or exiting a family home at a particular time in the morning; the route (time, speed and direction) taken by someone to work.

Simply replacing user identity with a single pseudonym is not sufficient to protect privacy. If an attacker has unrestricted access to fine-grained location information, it is often possible to determine which underlying identity is represented by any given pseudonym since publicly available data can be used to correlate pseudonyms with underlying real-world identities. Large amounts of correlating data are available from a wide variety of GISs; examples include the electoral roll, company and university websites, phone books and poorly protected databases connected directly to the Internet.

If location data is recorded at sufficient resolution, a single static pseudonym does not protect the privacy of an individual. To demonstrate this, two weeks of location sightings from an indoor location system were recorded using the Bat System. The Bat System (Ward et al. 1997) locates Bats, which are small wireless devices worn by people in a sentient office environment; position data for the Bats is recorded at 50 Hz with an accuracy of < 3 cm 95% of the time.

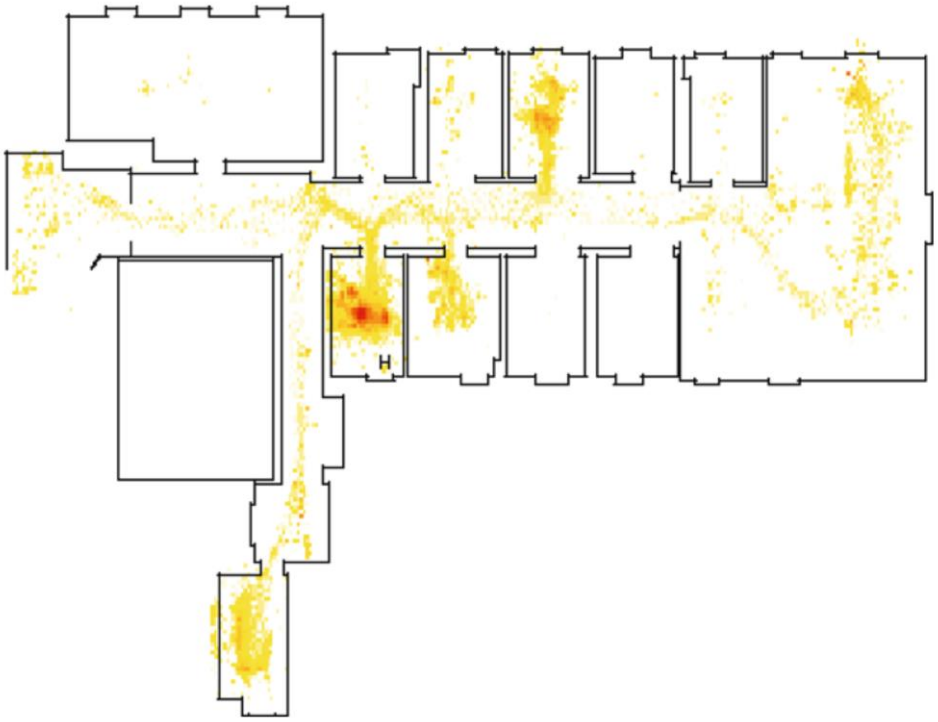


Figure 7.

Knowledge of a user′s primary desk location can be discovered by identifying the place where the Bat resides for the longest period of time; ′H marks the user′s home office.

Measuring the total time each pseudonym spent at every floor-plan position reveals that most occupants of a research lab spend the majority of time in a small contiguous area centred around their desk. These data can be extracted from the location information and correlated with known user desk positions to determine, with high certainty, the underlying user of any particular Bat; Figure 7 provides one such example.

Replacing user identity with a single, static pseudonym does not guarantee the user any level of anonymity (and therefore little privacy) if the location data associated with the pseudonym is of high temporal and spatial resolution. In this case, simply changing pseudonyms frequently may not be sufficient either: an attacker may be able to ″follow the footsteps” of the underlying users simply by matching a disappearing pseudonym with the nearest (in both the spatial and temporal sense) newly appearing pseudonym.

Location-aware applications often require much less spatial and temporal resolution and coverage area than the underlying location system provides. This, of course, is the exact reason why location service platforms provide a reduction in network bandwidth and processing requirements when compared with providing location information of all users directly to applications.

In order to prevent an attacker from correctly linking two pseudonyms to the same underlying user, the spatial and temporal resolution of the location data must be reduced in order to introduce confusion about the possible mappings of pseudonyms (i.e., prevent the linking of pseudonymous ″footsteps”). Resolution reduction can be applied globally

by reducing the spatial and temporal accuracy of all the location data provided by the location server to the location applications. For applications that require high levels of accuracy but reduced coverage area, it may be possible to constrain the resolution reduction methods to regions which are of little interest to the application. Broadly speaking, global resolution reduction techniques are suitable for stream-based applications, whereas coverage reduction techniques are suitable for event-based applications.

In order to guarantee user privacy through pseudonymity we need to limit the amount of information presented to applications to ensure: firstly, that the information distributed with any given pseudonym is not sufficient to identify the underlying real-world entity with sufficient certainty; secondly, different pseudonyms cannot be combined together to form a single pseudonym with sufficient information to identify the underlying real-world entity. Provided these two statements hold, we can argue, that no personally identifiable information has been made available to the application and thus information privacy is assured. There are two possible methods of achieving this.

Reducing the spatial and temporal quality of location information associates multiple pseudonyms with the same piece of location information. For example, given three pseudonym-location-time tuples from a location stream as:

(a,RoomSN13,14:52:23) (b,RoomSN17,14:52:25) (c,RoomSN17,14:52:29)

these could be modified to:

(a,Floor2,14:52:30) (b,Floor2,14:52:30) (c,Floor2,14:52:30)

These modified location objects then have an anonymity set size of three. Therefore resolution reduction introduces uncertainty as to the underlying identity associated with each of the pseudonyms and removes all simple home locations from the dataset. Gruteser and Grunwald (Gruteser and Grunwald 2003) describe in detail a method of reducing the accuracy of location information in order to protect privacy through anonymity. Beresford provides an analysis of their approach and provides some additional improvements.

Reducing the coverage area of location data given to particular applications can also be used to enable unlinkable pseudonyms. In the mix zone model. location applications specify a set of application zones for which they are interested in receiving location data. (This can be done, for example, as part of an event-based request from a location application to the location server.) A mix zone is defined as all the regions for which an application zone does not exist. Users entering a mix zone change their pseudonym, and therefore ″mix” with other users who are simultaneously located within the same region. An attacker viewing the movements of users into and out of a mix zone is then uncertain of precisely which users went where. Providing a measure of the level of anonymity provided to the users of the system is more complex than with resolution reduction. This is because every pseudonym entering a mix zone does not have an equal probability of becoming every exiting pseudonym. Therefore an information-theoretic measure is more appropriate than simply measuring the cardinality of the set of users inside the mix zone.

Conclusions

Technological developments have had a profound impact on the level of privacy experienced by individuals, and the rapid progress of computers in the 20th century has provided many new ways for governments, companies and individuals to invade both the collective and personal privacy of the individual.

Traditional GISs spatially index and cross-reference multiple datasets containing a wide variety of information and much of this data may be of a personal and private nature. Corporations and governments have used GIS technology to build geodemographic software systems in order to associate socio- economic attributes with particular geographic regions. Such databases may then be used for a wide variety of tasks, including urban planning and direct marketing; some individuals believe their use is discriminatory and invades the collective privacy of their community.

The ubiquitous computing revolution will change the way humans interact with computing systems; such systems which will gather, collate and distribute much more personal information than computers do today. Future GISs have a crucial role to play in supporting this new computer architecture because location data is a primary source of context information.

With the rapid decreases in cost and increases in performance, the average consumer is already able to store their personal information on a computer under their control; developments in broadband Internet connectivity will soon enable the consumer to share this data as part of a large-scale distributed system. This architecture presents individuals with the opportunity to manage their own personal data for the first time. However, integrating this decentralised architecture into location-aware applications is not always optimal, and some compromises must be made between protecting privacy and efficient use of location data in a ubiquitous computing environment.

Enabling privacy for GISs can be done through access control or anonymisation. Neither of these approach is perfect, and each has their advantages and drawbacks. Future GIS designers must consider the typical application usage scenarios and design the architecture of their computing infrastructure carefully in order to minimise privacy concerns.

Liability in the use of geographic information systems and geographic datasets

Introduction:

Liability is a subject of great interest and concern in the geographic information system (GIS) community. Use of GIS data and software inevitably results in some action or decision. If errors or shortcomings have resulted in inappropriate actions or decisions and parties are harmed, the specter of liability arises for dataset and software producers as well as for all other parties involved in handling geographic information.

As a general proposition, legal liability for damages is a harm-based concept. For instance, those who have been specifically hired to provide data for a database or those who are offering data for sale to others are responsible for some level of competence in the performance of the service or for some level of fitness in the product offered. If others are damaged by mistakes that a producer should not have made or by inadequacies that should not have been allowed, the courts have reasoned that producers should bear some responsibility for the damages. But for their mistake or defective product, the damages would not have occurred. In commercial settings, liability exposure often may be reduced through appropriate communications, contracts, and business practices. However, liability exposure may never be eliminated completely. Nor as a society would we want it to be. Modern societies generally support the proposition that individuals and businesses should take responsibility for their actions if those actions have unjustifiably caused harm to others.

However, the law does not require perfection. The law exists and responds to a realistic world. No general purpose dataset will ever be complete for all potential purposes that users might desire. Nor will the accuracy of data ever meet the needs of all conceivable uses. It is also inevitable that errors and blunders will be contained in any practical database. Thus, the law holds that those in the information chain should be liable only for those damages they had a duty to prevent. Establishing the nature and extent of rightful duties has traditionally been accomplished under theories of tort or contract law. Legislation may impose additional or alternative liability burdens. Legislation affecting liability for spatial datasets and software typically might be found in statutes addressing such issues as intellectual property rights, privacy rights, anti-trust issues, and access rights.

The liability in data, products, and services related to computerized geographic information systems is complicated by legal theory uncertainties surrounding liability for maps. This is compounded by the complexities and uncertainties in liability for information system products and services generally. Liability in GIS is further confused by the wide array of current and potential applications of geographic information technologies. Each application requires integration of information specific to the application and often will involve different attributes, analytical methods, spatial features, and accuracy requirements. The specific software and end users will also vary depending on the application to which the technology is being applied.

Thus, the complexity of the legal questions surrounding geographic information system liability combined with the diversity of problems to which geographic information technologies are being applied has tended to create diffuse, changing, and often undefined liability concerns for all parties involved in geographic information production and use.

People purchasing GIS software, datasets, products, and services are often disappointed in their expectations. Representations that software will accomplish certain tasks or that a dataset is complete or sufficient to accomplish specified tasks may be false or misleading. Datasets may contain errors and software may achieve inconsistent or wrong results. In these instances the disappointed purchaser or user usually has a contract relation with the technology product or service provider upon which to assert their claim. Thus, any discussion of liability with regard to GIS should probably begin with consideration of liability in the context of contract and licensing arrangements. Whether GIS products or services are custom-developed or software and datasets are sold prepackaged for the general consumer market, the relationships between the producer and purchaser or user will probably be affected foremost by contract law principles.

In disputes based on contract principles, the issue of warranty, either express or implied, will typically be raised as a basis of claim. In addition to warranty claims, the disappointed party may attempt to pursue a parallel tort claim, such as negligence, in order to expand the types and extent of damages that might be covered or to raise a broader range of duties on the part of the technology product producer. Also, statutes of limitations may vary.

Tort theories come to the forefront when the goal of the law is to prevent harms to the public generally. Thus, tort concepts such as negligence and strict liability may often be invoked by third party users outside of and independent of contractual considerations. Certain geographic information technologies and products if found defective may be held by public policy to be unreasonably harmful to persons or property if offered on the market to the public. In these instances, the tort theory of strict liability will be important.

In some instances, at issue may be an attempt by a dominant party to restrict the entrepreneurial activities of those entering into a contract with it. In such instances, antitrust (or noncompetition principles in a European context) may be relevant. Infringement of rights to intellectual property, personal privacy, and access to government information may also give rise to responsibility for damages.

Specific laws in regard to liability are dependent upon the specific laws of individual nations. This chapter uses as its foundation primarily U.S. legal principles. However, in an attempt to remain more general, the chapter focuses on "fundamental" legal principles and policies that remain germane regardless of the national jurisdiction. In a U.S. context, many of these fundamental principles are best illustrated through reference to the various Restatement of Law documents and the Uniform Commercial Code.

Contract liability concepts

A contract may generally be defined as a mutual assent between competent parties, usually manifested by an offer and acceptance, upon a legal consideration to do or to abstain from doing some act. The mutual assent may be express or implied and the legal consideration is often cash in a GIS context. Once a contract exists, a party to the contract may recover for breach of contract by showing the other party failed to perform as promised. It is not necessary to prove fault on the part of the breaching party. It is necessary only to show that the terms of the contract were not met. As a general proposition in regard to damages, parties are entitled to the benefit of their bargain and thus damages are calculated by determining the amount that would place the damaged party in the position that party would have been in had the contract been fully performed.

In the United States, contracts for the sale of goods are subject to Article 2 of the Uniform Commercial Code (UCC) which generally applies to all goods offered for sale in interstate commerce and has been adopted in entirety or large part by most states. If no explicit contract exists between a supplier of goods and a consumer, the law applies the provisions of Article 2 to the sales relationship. If an explicit contract for the sale of goods exists but is quiet in respect to certain items that were not addressed by the contract but that are now in dispute, the UCC fills in the gap to clarify the relationship between the parties. GIS software, hardware, and datasets typically qualify as "goods" and thus their sale often would be subject to UCC provisions. Of course, the parties to a contract have leeway to develop and agree to alternative provisions to those contained in the UCC. Contracts for the performance of services are not covered by the Uniform Commercial Code. Other nations often have similar default statutory provisions that apply when a sale is not governed by explicit contract language.

Warranties:

Warranties are often the issue in dispute in cases involving computer product contracts. The most basic warranty provided by a seller of goods is that the "(a) the title conveyed shall be good, and its transfer rightful; and (b) the goods shall be delivered free from any security interest or other lien or encumbrance of which the buyer at the time of contracting has no knowledge." Such a warranty may of course be negated by specific language that the person selling does not claim title to the product or modified to claim only partial title in the product being sold. Because geographic data sets may sometimes be acquired through a string of successive sources that may each alter the data set, a seller's ability to sell or license full interests in a geographic dataset may be an issue in some cases. Additional warranties may be express or implied.

Express warranties by the seller are created by the following:

(a) Any affirmation of fact or promise made by the seller to the buyer which relates to the goods and becomes part of the basis of the bargain creates an express warranty that the goods shall conform to the affirmation or promise.

(b) Any description of the goods which is made part of the basis of the bargain creates an express warranty that the goods shall conform to the description.

(c) Any sample or model which is made part of the basis of the bargain creates an express warranty that the whole of the goods shall conform to the sample or model.

"It is not necessary to the creation of an express warranty that the seller use formal words such as "warrant" or "guarantee" or that he have a specific intention to make a warranty, …"

Implied warranties are of two fundamental types, implied warranties of merchantability and implied warranties of fitness for a particular purpose. Under §2-314 UCC, a warranty that goods are merchantable "is implied in a contract for their sale if the seller is a merchant with respect to goods of that kind."

(2) Goods to be merchantable must be at least such as

> (a) pass without objection in the trade under the contract description; and ….
>
> (c) are fit for the ordinary purposes for which such goods are used; and
>
> (d) run, within the variations permitted by the agreement, of even kind, quality and quantity within each unit and among all units involved; and
>
> (e) are adequately contained, packaged, and labeled as the agreement may require; and
>
> (f) conform to the promise or affirmations of fact made on the container or label if any.

(3) .... other implied warranties may arise from course of dealing or usage of trade.

Implied warranties of fitness for a particular purpose are established under the language of §2- 315 UCC. "Where the seller at the time of contracting has reason to know any particular purpose for which the goods are required and that the buyer is relying on the seller's skill or judgment to select or furnish suitable goods, there is unless excluded or modified under the next section an implied warranty that the goods shall be fit for such purpose."

Language in the contract tending to negate or limit an express warranty is construed whenever reasonable as consistent with the express warranty but where consistent construction is unreasonable the negation or limitation is inoperative. Implied warranties of merchantability and implied warranties of fitness may be waived in the contract. Warranties "whether express or implied shall be construed as consistent with each other and as cumulative …"

Warranties in GIS Cases

Scenario 1 - Let us assume that an individual has purchased off-the-shelf GIS software from a merchant. The purchaser leaves the store, tries the software, and is disappointed in her expectations of the capabilities of the software. The product carries with it an implied

warranty of merchantability as well as potential express warranties that might be included, for instance, on the packaging. Whether the purchaser may receive return of her purchase price will depend on whether these warranties have been breached. Software, system and data sellers typically are able to avoid damages for breaching implied warranties of merchantability by meeting the requirements of §2-314(2) of the UCC listed above and are able to avoid damages for breaching express warranties by not blatantly overstating or misrepresenting the capabilities of their products. Thus, in the typical business-like sale of prepackaged software or data it is unlikely that these warranties have been breached. Of course, further consumer laws in some jurisdictions or custom in the trade may allow return of undamaged products within specified time periods with no need for explanation. There is also considerable case law authority supporting the invalidity of "shrink-wrap license" provisions under U.S. law and therefore a waiver of merchantability contained in a license inside of a software or dataset package probably would be unenforceable against a consumer.

Scenario 2 - In another instance, let us assume that an individual is engaged in the business of selling health care products by mail. She reads sales literature about a GIS database and software system that will allow her to better profile her potential customers and their physical relationships to a wide range of environmental hazards. Updates of information on the purchasing patterns of households and environmental hazard ratings are provided on a regular bi- weekly basis under the terms of her license with the system supplier. Her signed standard-form license supplied by the system supplier states that "the software system and data are supplied AS IS without warranties of any kind, either expressed, implied, or statutory, including but not limited to warranties of merchantability and fitness for a particular purpose." After suffering greatly decreased sales through her latest mailing efforts, as evidenced by her worst sales in ten years, she discovers that a recently introduced non-intentional defect in the latest version of the GIS software has resulted in her mailings going to the least likely purchasers of her health care products rather than the most likely purchasers. From her perspective, the software did not do what the sales literature promised and resulted in very substantial losses to her business.

Unless she lives in a jurisdiction that bans the exclusion of implied warranties, she may have little chance of prevailing on a contract claim since all warranties were explicitly waived in the contract. She might argue that the contract as a whole was so one-sided at the time it was made that it was unconscionable under the circumstances. However, let us assume for the sake of argument that the court finds otherwise, perhaps because the contract was among reasonably sophisticated business parties of relatively equal bargaining power and the parties freely negotiated the terms of the contract or had a reasonable opportunity to do so. This raises the question of whether a tort action based on negligence, misrepresentation, fraud, or strict liability might be brought in lieu of or in parallel with the contract claim.

Tort liability concepts

A tort is a private or civil wrong or injury to a person or property, which does not arise as the result of a breach of contract. There are no fixed and rigid classifications for torts. Two major policies supported by tort law are punishing wrongdoers for their conduct and compensating injured parties. If both policies can be supported by transferring money from the wrongdoer to pay for the damages of the party harmed, the rationale is strong for granting tort relief. Although there are no rigid classifications for judge-made tort law, there are some traditionally recognized or classic tort situations. Three traditional classes of tort liability have been for intentional harms, negligence, and strict liability. Additional

classes of claims that may be relevant to disputes involving GIS products and services include products liability, defamation, wrongful invasion of the right of privacy, and misrepresentation. The primarily judge-made law of torts has been summarized in the U.S. in Restatement of the Law (Second) Torts. Legislation relative to tort law in individual states has often mirrored the provisions of this document.

Negligence

Negligence is conduct that breaches a duty of care for the protection of others against unreasonable risk of harm. Each person owes a duty to act as a reasonable person would under the same or similar circumstances. Thus, negligence does not involve intent to cause harm but only failure to meet a sufficient degree of care. The greater the risk of harm involved, the greater the care that a reasonable person can be expected to take. Under negligence, the duty to act reasonably to avoid foreseeable risks of physical injury extends to any person. If this duty is breached, a plaintiff can recover for personal injury or property damage caused by a product. However, purely economic loss is not typically recoverable in a negligence action. The duty to avoid foreseeable risks of solely economic injury runs only to those with whom the product producer has a special relationship.

In some situations the defendant is able to present a defense that the plaintiff's own actions failed to provide sufficient self-protection. In such cases, a combination of the plaintiff's and defendant's actions may have caused the injury and, if so, liability for damages is distributed among the parties using the doctrine of comparative negligence or the older doctrine of contributory negligence.

In most instances, those whose cause of action against a GIS product or service provider is based solely on economic damages will have a contractual relationship with that provider. For instance, even under principles that support extension of contract warranties to other reasonably foreseeable users of the product, those parties without a contractual relationship would typically be excluded from claiming for economic loss unless they were also injured in person. Since negligence claimants seeking only economic damages would in most cases also have a contract with the GIS product provider, this raises the issue of whether they might bring a parallel action in negligence or bring such an action in lieu of a contract claim. Remember that plaintiffs often desire to pursue tort claims such as negligence because of the possibility for expanded damages and a broader range of duties imposed on the defendant.

The traditional test in allowing a negligence action in parallel with the contract action for breach of a duty established by the contract was whether there was misfeasance (improper performance) as opposed to nonfeasance (failure to perform.) In nonfeasance or nonperformance, one may only resort to contract damages.

Another possibility for maintaining a parallel negligence action would be through a claim of "professional malpractice." Malpractice occurs when an individual does not perform to the expected standards of one's profession. Professional standards of care are higher than those imposed on the average citizen. Under this approach the plaintiff would argue that a duty independent of the contractual duty arose in the specific instance. The plaintiff would argue that a "special relationship" existed between the parties. Proving such a relationship would involve showing that the plaintiff was relatively unsophisticated, the plaintiff needed to depend on the defendant's expertise, the plaintiff did depend on that expertise, and the defendant held itself out as having the required special expertise. If shown, the plaintiff could maintain both breach of contract and negligence claims.

Negligent and Fraudulent Misrepresentation:

Liability for negligent misrepresentation is established by Restatement (Second) of Torts § 552 as follows:

> One who in the course of his business, profession or employment, or in any other transaction in which he has a pecuniary interest, supplies false information for the guidance of others in their business transactions, is subject to liability for pecuniary loss caused to them by their justifiable reliance upon the information, if he fails to exercise reasonable care or competence in obtaining or communicating the information.

Liability for fraudulent misrepresentation is established by Restatement (Second) of Torts § 525 as follows:

> One who fraudulently makes a misrepresentation of fact, opinion, intention or law for the purpose of inducing another to act or to refrain from action in reliance upon it, is subject to liability to the other in deceit for pecuniary loss caused to him by his justifiable reliance upon the misrepresentation.

Perritt argues that in a contract setting establishing the duty in a misrepresentation case above and beyond what the contract requires of the parties is often very difficult. He additionally argues that "the modern law of fraudulent misrepresentation is only subtlety different from the modern law of breach of contract." He makes this argument both in regard to damages recoverable and in establishing the elements of the case. As such, when a contractual relationship exists there would appear to be only infrequent situations where it would be beneficial to pursue a misrepresentation claim over a contract claim. One instance might be where the time to bring a cause of action has passed the statute of limitations for bringing tort claims but not a longer statute of limitations for contract claims.

Fraud in the Inducement

The complexities and confusion caused by bringing a tort action within a contract setting and the tendency of courts to defer to the written contract as the final agreement between the parties sometimes may be overcome by claiming "fraud in the inducement" of the contract. The objective of the plaintiff in such an action is to focus the courts attention solely on the events that occurred prior to and separate from the contract. Alleged fraud, such as evidenced by fabricated testimonials or test results, that occurred before consideration of a contract could justifiably be considered as tortious conduct separate from the contract. The wrongful conduct led the party into a contract which directly resulted in damages. Fraud in the inducement may be pursued independent of contract claims. Thus, by this approach the plaintiff advocates disposition of the dispute by establishing duties and breach of duty standards through tort concepts and ignoring the contract language, except perhaps in evidencing the amounts and kinds of damages suffered.

Strict Products Liability

For public policy reasons, suppliers of defective products are often held strictly liable to consumers and other product users for injuries caused by defective products. The primary objective of strict products liability theory is to provide an incentive to manufacturers to keep unsafe defective products off the market. The incentive is provided by reducing the burden of proof on harmed parties and making the manufacturer and others in the supply

chain responsible for damages caused by unsafe defective products. If only negligence theory applied, suppliers could often escape liability for defective unsafe products by showing that industry-wide standards for design and manufacture were reasonably met. A product might be unsafe, yet still meet usual industry standards for quality control and design.

Restatement of the Law (Second) Torts §402A states that:
(1) One who sells any product in a defective condition unreasonably dangerous to the user or consumer or to his property is subject to liability for physical harm thereby caused to the ultimate user or consumer, or to his property, if

> (a) the seller is engaged in the business of selling such a product, and
>
> (b) it is expected to and does reach the user or consumer without substantial change in the condition in which it is sold.

(2) The rule stated in Subsection (1) applies although

> (a) the seller has exercised all possible care in the preparation and sale of his product, and
>
> (b) the user or consumer has not bought the product from or entered into any contractual relation with the seller.

Under a strict products liability approach there is no need for the harmed party to show that those with a financial interest in placing the product on the market were negligent in the design or manufacture of the product. Showing the defective condition, that it was unreasonably dangerous, and that it caused the physical harm suffered is sufficient. The duty of a product provider in such an instance is to any reasonably foreseeable member of the public that might be harmed by the good. Fault is not a required element of the cause of action under strict liability and therefore waivers and disclaimers of fault that might be contained in a contract between the supplier and the consumer are ineffective because they are irrelevant to the cause of action. Other courts have held such disclaimers not to be irrelevant but to be invalid in consumer transactions as against public policy.

Although liability is strict in such instances, it is not absolute. There is no award of damages for purely economic injuries. There must be physical injury and the plaintiff must prove that a defect attributable to the defendant caused the injury. Defects may be due to manufacture or design. A manufacturing defect results when the finished product is not in the condition the manufacturer intended it to be when it left its control. A design defect is one that causes the product to carry an inherent risk of harm in its normal use.

If a physical injury occurs only to property, the question often arises whether the physical injury is of such a nature that the claim warrants inclusion under strict products liability theory. The clearest cases appear to be those in which property damage involved a safety hazard that could readily have caused personal physical injury to a consumer or other user even though in the case at issue it caused only physical injury to property. That is, the nature of the defect and the type of risk involved in causing the physical injury to property are so closely associated with potential physical injury to persons that the underlying goal of preventing such hazards would be frustrated if the physical injury to property is not included within the ambit of strict liability.

Other courts determine whether physical injury to property without physical injury to persons falls within the ambit of tort law primarily by looking at the relationship among

the parties. A "garden variety" consumer has very little bargaining power and therefore some courts, on public policy grounds, allow consumers to sue in tort rather than restrict them to breach of warranty actions. Thus a consumer with little bargaining power that has suffered physical harm from a defective product should be able to pursue a strict liability cause of action in these jurisdictions. This may be true even for a commercial consumer assuming the commercial consumer has little expertise in the product and the product was offered "as is" with little or no bargaining involved. If a party has little bargaining power, sound public policy also indicates that the consumer also has no power to disclaim their right to seek redress under strict liability principles.

Several court cases in the U.S. have indicated that the imposition of strict liability should be allowed in electronic maps and charts. The language of these cases justifies including electronic charts and maps while excluding how-to-do books from the realm of strict liability by distinguishing charts and maps as technical tools whereas how-to-do books are more in the tradition and nature of providing ideas and expressions. At least one commentator suggests that this distinction is not very useful. He suggests that distinguishing practical works that lead people to depend on a work product for taking direct physical action is a more reasonable way to determine which products should be considered within the ambit strict liability. Whether treated as a technical tool or a practical work that leads people to take action, electronic charts and maps seem to be well within the bounds of the type of information product reasonably considered under strict liability principles.

Damages are recoverable for direct injuries such as medical expenses, lost wages, property damages, and pain and suffering. Losses which are solely economic without physical injury are generally not recoverable under strict liability.

Tort Liability in GIS Cases

Scenario 2 - In scenario 2 discussed previously, the only damages alleged by the health care products distributor are economic. In that case the clear showing of a defect in the software that resulted in the system malfunctioning rather than not working may be sufficient to meet the requirement of misfeasance. If so, this would allow the parallel action in negligence and raise the possibility of recovering damages beyond those allowed under contract liability principles. However, even if negligence is found in failing to meet the requisite duty, the fact remains that the waiver of express and implied warranties in that specific contract might still be upheld.

Scenario 3 - Let's assume that a small two person "timber finding" business reads about the possibilities of finding pockets of hardwoods through the use of GIS and image processing software in combination with satellite imagery. A large GIS consulting firm advises the timber finding business that they have already developed the system that the timber finding company needs, they have numerous clients using the system, and those clients have all increased their hardwood finds by at least 200% over conventional ground cruising methods. The timber finding business enters into a contract with the GIS consulting firm for delivery of a fully operational system including the imagery they need for the large land mass that they are interested in investigating. The signed contract between the parties states that "damages recoverable by the purchaser in the event of a breach of this contract by the seller are limited solely to return of the price of the contract." The GIS consulting firm fails to provide the system and in fact no system has ever been developed. The timber finding company relies on the consulting firm's promise to deliver the system on time and suffers substantial reliance damages due to timber

finding contracts it was forced to breach because the new capabilities were not delivered as promised.

Discussion: In this case the claimed losses are solely economic. They are arguably the result of nonperformance as opposed to improper performance. Thus, the traditional test for allowing a negligence action in parallel with the contract action is not met. Yet, the plaintiff would still prefer suing in tort since tort actions may allow the possibility for a greater range of damage recoveries.

One approach that the timber finding company might take is to argue the malpractice claim that a duty independent of the contractual duty arose in this specific instance. In arguing the "special relationship" elements of such a case the timber finding company would argue that their company is relatively unsophisticated, they needed to depend on the expertise of the consulting company, did in fact do so, and the consulting company held itself out as having the required special expertise to implement the complex technological system for them. If the court rejects these arguments, defers to the contract as the final agreement between the parties, and holds that the contract is not unconscionable, the provision limiting the contract damages is likely to be upheld.

Negligent or fraudulent misrepresentation may also be potential causes of action in the case. If the plaintiff can prove through a preponderance of the evidence the misstatements of facts as alleged, they probably have a good case for fraudulent misrepresentation. For instance, evidence of fabricated written testimonials of the other purported clients of the GIS consulting firm would be solid evidence of fraudulent intent and misrepresentation of facts. If the only evidence of fraud is oral, the danger exists that oral statements prior to the contract will be treated as "puffery" on the part of the seller which any reasonable purchaser should have treated with caution and the court may lean toward the contract as evidencing the full and final agreement between the parties.

A claim for "fraud in the inducement" of the contract also offers possibilities for success by the plaintiff. Here the objective is to convince the court that the alleged fraud involved separate and distinct actions prior to and extraneous to the contract. If the court is convinced that the fraud was a sufficiently separate occurrence there is less likelihood of deferring to the contract language to resolve the matter. This would undoubtedly be to the plaintiff's benefit as it would avoid imposition of the contract language limiting damages.

Scenario 4 - Assume that a farmer buys a "precision farming" system consisting of software, computer hardware, and computerized variable rate farming equipment from a large equipment manufacturing company. The new computer controlled system tracks the location of farm machinery very precisely through the use of a global positioning system receiver mounted on the farm equipment and is able to apply fertilizers, pesticides, and herbicides at variable rates in order to match the needs of the soil and groundcover conditions as identified in a digital spatial dataset for the farmers fields. The system is also able to measure the productivity of each square meter of soil as crops are harvested. The farmer hires a local engineering consulting firm to accomplish soil tests in a dense grid over his fields and to insert this information along with other physical data specified by the manufacturer into the computerized system. The farmer implements precision farming of his fields. After one of the best growing seasons on record, the farmer experiences one of the worst crops he has ever had. Through an investigation the farmer discovers that chemical fertilizers, weed sprays, and insecticides were sprayed by the automated machinery in reverse locations to where they were needed due to a software error in the latest version of the software. The inappropriate spraying resulted in

poisoning of the ground in some areas, killing off the crop in other areas, and allowing insect infestations in other areas. Evidence shows that the engineering firm made no errors in data collection and inserted the required information as directed by the manufacturer's instructions. The farmer's standard form contract supplied by the instrument manufacturer states that "the software system and data are supplied AS IS without warranties of any kind, either expressed, implied, or statutory, including but not limited to warranties of merchantability and fitness for a particular purpose." The software component of the system containing the defect was developed and distributed by a very large GIS software company with whom the farmer did not have a direct contract.

Discussion: Under contract principles, the farmer might pursue breach of implied warranties of fitness for use and merchantability as well as any express warranties that might have been made. However, to pursue these warranties the farmer would have to overcome the clause in the contract stating that the "software system and data are supplied AS IS without warranties of any kind ..." The farmer might argue that the contract clause on its face is unconscionable since application of the disclaimer clause would allow the system producer to provide useless and harmful systems to consumers without any responsibility for the harm caused by the systems nor any contract benefit for the consumer. If the court as a matter of law finds the clause to have been unconscionable at the time it was made, the court would probably limit the clause as to avoid any unconscionable result. Resort to normal contract principles in deterring damages would then seem appropriate. Deeming the entire contract unconscionable with resort in entirety to negligence principles for resolving the liability issues would appear to be inappropriate, except perhaps if the court found from the evidence an extreme disparity in bargaining power between the parties.

Because the dispute involves improper performance as opposed to nonfeasance, the possibility of pursuing a parallel negligence claim with the contract claim exists. Negligence in this case arguably involves both physical harm to property as well as economic damages. It appears reasonably foreseeable that a software error could cause physical damage to farmland and crops if the software was used in conjunction with computer controlled farm equipment as intended by the suppliers and as used under normal conditions as was done in this instance. Although pursuing a negligence claim in parallel with a contract claim is complex and gives rise to difficulties in meeting the conflicting underlying objectives of tort law versus contract law, protecting the public against the hazardous harms caused by this type of defect and the argument that suppliers are in a better position than users to insure against the losses caused by defective products may be reason enough to allow the parallel action.

It is also interesting to explore whether a strict products liability claim might be successful in the instant case. Although no person was physically injured by the defective product, the fact situation seems to meet the requirements of Restatement of Law (Second) Torts § 402A of being "unreasonably dangerous" to a user's property. The software defect is arguably more in the nature of a "manufacturing defect" than a "design defect" in that the defect was unintended and didn't meet the software developer's own standards. The cost and feasibility of testing the software to see if it worked properly and to correct it prior to its release to consumers seems very small compared to the risk of physical injury and the gravity of potential harms that might be caused by the malfunctioning of the system. The software developers and the machinery manufacturers were fully aware that their products would be used in the application of dangerous farm chemicals. Although the physical harm was to property only in this instance, the hazard

and defect represent a significant safety hazard to humans as well. Because of the inherent safety hazards and because of failing to establish safety conditions designed to avoid unreasonable risks of harm, the type of physical damage involved seems to be of the type that should be allowed to be included within the ambit of strict liability.

Section(1)(b) of §402A additionally requires that the product "is expected to and does reach the user or consumer without substantial change in the condition in which it is sold." Although a complex combination of farm machinery, computers, software, and data contributed by various parties was required to make the system operational, the individual components were not altered by the user. The software containing the defect remained unaltered by the consumer. Thus, those in the chain of generating income from the sale of the precision farming system should not be able to escape their duty to provide a safe product by claiming that the system was changed when applied to a specific farm site. The system was implemented in conformance with the manufacturers instructions and the application of the system to a particular site did not involve substantially changing the condition in which it was sold to and received by the farmer.

Scenario 5 - Assume that a car manufacturer installs a vehicle routing system in its latest line of automobiles. Drivers are able to insert a CD containing detailed street, address, and business information for a community and are able to have the computerized system select a travel route for them based on selected criteria such as shortest time, shortest travel distance, or all streets of a certain type. The location of the vehicle is tracked as it travels primarily through use of a global positioning system receiver and the system uses oral voice commands to inform the driver when an exit is coming, features of interest along the route, turn right, turn left, etc. An engineering firm has collected street and business data for a local community, has placed it on a CD, and the CD is now being used by consumers in routing themselves through the metropolitan area. It appears that all data collected by the engineering firm is spatially accurate and all other information such as street names, street directions, names of businesses, locations of traffic lights and signs, and similar physical features was accurate when collected. The owners manual for the system indicates that the system is provided solely as an aid for determining routes and warns that drivers should rely primarily on their own observations to check the oral routing instructions against potentially conflicting traffic and street conditions. A similar abbreviated notice is provided on the dashboard.

A thirty year old male driver bought the CD at a local discount store and has been using it for several months to aid him in routing himself through the city to deliver flowers in his part-time job with a small florist. After typing in the addresses of his deliveries for the day, the system calculates a route. Half way through his deliveries the system gives him oral instructions to turn right at the next street. He turns right and drives down a major one-way street in the wrong direction. This results in a head-on collision with another vehicle and he receives major physical injuries. Upon investigation, it is determined that no data was entered into the system wrongly nor was there a malfunction in the software. Rather, it is determined that the street recently was changed from a two-way street to a one-way street by the city.

Discussion: Under the facts, there is no manufacturing defect in the provided vehicle routing software nor in the separately purchased dataset. However, the injured party may argue that the system was defectively designed and poses too great a threat to physical injury from a safety hazard perspective as designed and implemented. Any reasonable system designer should have known that the directions of streets, locations and kinds of traffic controls, and similar physical features affecting safe routing decisions could be

expected to change over time and the system and data providers should have provided a means to update the information when it changed. It may be argued that the system is so unreasonably dangerous with the current design defect that it should never have been placed on the market. Placing it on the market should have been delayed until such time as remote data upgrades to such systems could have been reasonably and responsibly provided or the CD should have been sold under a license agreement with data upgrades going to the address of the currently registered owner of the vehicle. The gravity and likelihood of harm due to the inability to provide reliable data upgrades far outweighs the social benefits of such systems.

Counter arguments are that the system is unavoidably unsafe in certain very limited situations but the overall social utility of vehicle routing systems is so great that they should not be kept off the market simply because the technology hasn't advanced to the point where the systems are able to be made fail-safe. Unavoidably unsafe products are not "defective" when the danger is reasonably apparent and the danger of full reliance on oral directions from a computerized system should have been obvious. Adequate warnings were provided. It was the plaintiff's unreasonable misuse of the product that caused the "defect" and therefore no defect exists and no cause of action exists without that unreasonable misuse.

In the U.S., courts typically would resort to one of three risk-utility analysis methods to determine whether the design should be deemed to be defective. Depending on the jurisdiction, plaintiffs and defendants would couch their arguments to address a pure negligence standard, a state-of-the-art analysis, or a consumer expectations test. If the jury did find the system to be in a defective condition unreasonably dangerous to the user and found the defect to be the cause of the injury, those jurisdictions following comparative negligence approaches for determining the distribution of damages probably would reduce the award to the plaintiff by the plaintiff's proportionate share of responsibility in causing the injury as determined by the jury.

Summary:

Liability is a creation of the law to support a range of important social goals such as avoidance of injurious behavior, encouraging the fulfillment of obligations established by contracts, and the distribution of losses to those responsible for them. If decisions are made based on geographic data or products produced by other than the user, there will always be liability exposure. Minimizing losses for users of geographic data products and reducing liability exposure for creators and distributors of such products is achieved primarily through performing competent work and keeping all parties informed of their obligations.

Liability in data, products and services related to geographic information systems is likely to be determined in most instances by resort to contract law and warranty issues. This is true whether geographic data products are custom developed for specific clients or mass produced for the general consumer market. Tort theories, such as negligence and strict liability, come to the forefront when preventing harms to the public generally arises as an issue.

In this part, fundamental contract and tort liability concepts were reviewed followed by illustrations of how liability issues might arise and be addressed in a range of GIS conflict scenarios. Liability burdens arising under legislation relating to specific substantive topics such as intellectual property rights, privacy rights, anti-trust laws, and open records laws were not addressed by the chapter. Assessing liability exposure arising under statutory

law requires consideration of the specific language of the legislation in each nation or other jurisdiction. In addition, this chapter did not address the potential immunity of government agencies from liability for their geographic information products. Again, the availability of immunity for government agencies from damages varies among nations. Finally, even though many geographic information products are being transferred across international boundaries and geographic data forms a significant component of the global information infrastructure, this chapter did not address the likely effects of international agreements on liability for injuries resulting within world trade contexts. All of these additional issues should be considered when relevant to geographic information supplier and consumer relationships.

Some legal concerns with the use of crowd-sourced Geospatial Information:

Introduction

Spatial law and policy occupies a fascinating phase in technological development as new legal relationships and operational imperatives arise. The ′grey areas of interpretation and respective responsibilities are set to become more prominent. Geospatial information has been transformed by ′disruptive technologies (′innovative′) that have dictated a new modus operandi, from the collection of spatial data, storage, analysis to its use in information systems. The previous use of the floppy disk and compact disc (CD) to exchange data and information has given way to the universal service bus (USB), flash drives and cloud computing (CC). The displacement of CDs and digital video discs (DVD) as a storage media by CC has potentially made these physical media redundant. The information technology evolution has also witnessed innovative uses of the Internet from Web 1.0 to Web 2.0. In its latest guise, many new possibilities have emerged including the sharing of maps and spatial information in one common storage medium – the ′cloud′.

This paper outlines some preliminary findings and concerns that are caused by disruptive technologies. The literature has prominently focused on technology and apart from Scassa (2013), little attention has been paid in previous studies to legal concerns. This paper posits the view that there are many uncertainties that may need to be resolved before the operational and technological innovations may be deployed on a large scale. In part 2 of this paper the Web 2.0, crowd-sourced maps and produser environment is described. This discussion leads to parts 3, 4, & 5 that raise concerns with the quality of data and information, ownership especially of intellectual property rights, and legal liability in contract and tort respectively. The potential risks for each of these concerns have to be appropriately managed. Part 6 examines current legal frameworks and the legal governance of the collection and dissemination of geospatial data. The final part 7 summary and conclusion identifies five observations and suggested actions that may be taken to resolve the practical problems for produsers. Many of the findings reported and discussed here are preliminary ones but nevertheless provide a basis for proposing a governance framework for all parties.

Web 2.0, Crowd-sourced Maps, VGI and Produsers

This section lays the groundwork for a common understanding of the Internet environments beginning with Web 1.0 through to the collaborative milieu of Web 2.0 with innovative ways of harnessing the myriad applications. In particular, the spatial dimension and its mapping and recording is of particular interest especially with

volunteered geographic information (VGI) and the different producers and users as participants in crises, emergencies and disaster management.

In the Web 1.0 environment, the World Wide Web (WWW) known synonymously as the Internet was envisioned by Sir Tim Berners-Lee as ″a collaborative medium, a place where we [could] all meet and read and write". Recent developments on the Internet and especially within Web 2.0, have extended the range of use – from the desk-bound to the mobile device. However, the more ubiquitous ′application (apps) of mobile electronic devices has produced new legal concerns in general and liability in particular. More specifically, net-citizens (netizens) who contribute to the collection, use and dissemination of geospatial information have triggered a re-evaluation of traditional legal frameworks. The legal and policy framework is continually being cajoled to adapt the law to provide novel solutions for the digital age.

In the Web 2.0 environment the static pages of websites are used and updated by collaborative and cooperative means by users for dialogue, creation of content, and the online meeting of virtual communities. The new environment and other mobile technologies have opened up the landscape for nearly everyone to access the Internet, to create and share content. There is a democratisation in the production of information.

In this environment communication takes place anytime and anywhere. However, the management of such activities will invariably be a place-based where ′jurisdiction becomes pre- eminent and the law of the land prevails. In the absence of specific laws to govern electronic-based activities in a jurisdiction, existing law and regulations may have to be adapted to cater for and address new challenges of technology. The adaptation of the law could be by way of analogising case by case or re-writing rules and regulations for ′special or exceptional cases′.

Furthermore, innovative ways of collaborating and disseminating information have been created to harness the dynamic power of Web 2.0. Paper maps have made way to electronic maps together with the so-called ′crowd-sourced maps. Ushahidi (′witness in Kiswahili) is the interactive map that was developed by concerned citizens during the disputed Kenyan elections of 2007. The interactive maps provided eyewitness accounts of violence across Kenya. The maps were accompanied by written text in Ushahidi and images were displayed on Google Maps. This example demonstrates the potential applications that could assist first responders and humanitarian organisations in the wake of natural disasters, crises and violent conflicts.

Volunteered geographic information (VGI) is ″the widespread engagement of large numbers of private citizens, often with little in the way of formal qualifications, in the creation of geographic information". VGI is part of a broader trend of ″user-generated content" (UGC) that is becoming commonplace in Web 2.0-based applications. The VGI community is set to play an influential role in modern map making and they have sometimes been described as produsers defined below.

Produser is a portmanteau of two words combining ′production and ′usage − a word popularised by Axel Bruns (2008). The word refers to the type of user-led content creation that takes place in a variety of online environments such as Wikipedia. There is the blurring of boundaries between producing and using, hence the produser.

Examples of other VGI include need for information and maps in crisis situations, for example, during the Haitian earthquakes of 2010. Volunteer mapping efforts that assists

in relief efforts have since been used in the context of forest fires, floods, hurricanes and other disasters. Volunteers capture and record information using mobile devices and submit these to a website or central agency that analyses, reviews and then publishes the data on base maps, for example, those provided by OpenStreetMap or GoogleMaps. Most of these contributors are novices and non- professional map creators. While reliability and accuracy of VGI might be questioned, the timely production of near-instantaneous maps during times of crisis has proven invaluable. Further examples of VGI include the Libyan crisis map in 2011; the United Nations Organisation for the Coordination of Humanitarian Affairs (UNOCHA) maps; Transparency Morocco; Mamdawrinch; and Syrian Tracker 2013.

Scassa (2013) identified a series of potential risks from the perspective of the operator of a VGI site, the contributor of VGI and user of the product, service or application that is created using VGI. The article gave an overview of emerging issues of which developers, contributors and users should be aware when engaging in VGI-related activities. The lessons for all are timely.

The digital environment has made nearly everyone with a mobile device a map maker and a digital recorder. Nearly every phenomenon that is observable may be captured and mapped. Using cell phones, global positioning system (GPS) devices and placing information on the Internet using social media has elevated the importance of the spatial context. The newly discovered cartographer may be untrained in geographic information systems (GIS) technology but are now enabled to contribute to location-based services and bringing GIS to the masses.

While expectations are on the rise, so are the legal risks. Legal liability questions have been raised where the subscribed data might be biased and wrong leading to an endangerment to life. VGI service providers on their part have to ensure that they do not engage in conduct that is deemed ″negligent" and to verify volunteer contributions.

The ubiquity of location-aware devices that automatically record personal movements, habits and other information linked to one′s location raise other concerns such as privacy. Equally important are those relating to the ownership of geospatial information and the kinds of tacit agreements between producers and users.

Many of these questions have remained largely in the background, lightly discussed and seldom highlighted. In the following three sections, issues of quality of data and information, of ownership and of legal liability are reviewed to help prepare a proposed legal framework.

Concern # 1 Quality of data and information:

Amongst the range of potential risks is the concern with the quality of the data contributed by the ′crowd relative to those produced by professional mapping agencies. Data authoritativeness is closely linked to the background and training of the contributors. Traditional government sources of GI have always been considered more ′authoritative because of the professional training and other quality checks in place. What is considered authoritative geospatial data may be debatable and appropriate criteria may be necessary.

However, what is not in dispute is that the production of authoritative geospatial data is costly, time consuming and usually undertaken by the public sector. Evidence suggest that many government mapping agencies might be struggling to obtain continuing funding to maintain geospatial data or the mandate to keep geospatial databases current.

As a result it it seems that there may be a growing reliance on VGI data. While on the one hand, VGI data sources could be highly accurate, complete, in time and at a practical useable scale, the potential risks are still largely unknown and little understood.

The life cycle of GI from the collection of data, cleansing, and assembly of results are prone errors and inaccuracies. Without careful editing and ground-truthing inaccuracies might creep in through misinterpretation of observations, digitising errors, resampling and the use of incorrect map projections as well as the inexpert final assembly of results. For VGI data to be readily acceptable the issues of quality control and monitoring of VGI contributions are a prerequisite as the risks are neither hypothetical nor inconsequential. Tragic consequences could ensue from using ′bad data.

The Canadian the Centre for Topographic Information, a division of Natural Resources Canada, has begun assessing the potential of a collaborative mapping model that combines contributions from provincial and municipal organisations as well as those from its citizens. In Australia, the state of Victoria′s Department of Sustainability and Environment has developed a Notification and Editing Service that encourages crowd-sourcing of GI. The OpenStreetMap Collaborative Prototype (OSMCP) project of the U.S. Geological Survey (USGS) and swisstopo [sic] Revision Service of the Swiss Federal Office of Topography are experimenting with similar ideas.

In the U.K. OpenStreetMap (OSM) is one of the better known examples of collecting and leveraging VGI. Initiated in 2004, the project was a response to the strict copyright laws that apply to Ordnance Survey maps and geospatial data. With OSM any interested party may view and edit geographic data in a collaborative way. Registered contributors may make additions, modify inaccurate features, delete stale or invalid data and generally edit features to improve the quality of the geospatial database. In addition to individual contributions, organisations have donated complete data sets to OSM. Ironically OSM does not use quality control experts to vet contributions. The quality of the data is refined over time through iterative corrections of the submitted data by subsequent contributions.

The concerns about the quality of data also raises issues about who owns the contributed geospatial data in the mix. The rights to ownership of the intellectual property can be a ′real issue especially when the end use is transformed from the altruistic ideals to the for-profit motives.

Concern #2 Ownership: Intellectual property and moral rights:

Intellectual property rights (IPR) including the ownership of copyright is a pressing concern with VGI data. In most common law jurisdictions copyright is vested in the author of an original work that is the expression of an idea that also involves a degree of skill and judgement in the work.

In the U.S. ′originality focuses on a creative spark, rather than on the ′sweat of the brow′, whereas, in Canada ′originality requires skill and judgement and not copied from a previous idea.

With electronic databases, concerns have been raised about whether the ′arrangement of data qualify as sufficiently original. The views here may be contrasted to database protection laws in the EU especially the sui generis regime where protection is afforded not just to an original selection or arrangement of the data (similar to copyright law) but to the underlying data itself. In VGI applications and its products there may be

independent rights in the underlying base map. Given the nature of any map is made up of layers of information there can conceivably be multiple copyright holders in any given work.

With many contributors adding to the volunteered geospatial database, there can be difficulties in tracing the heritage of the data and hence the ownership of the copyright. The ′confected or synthetic data may ′lose copyright status because of the difficulties associated with tracing the current and original owners of the data. It has been suggested that Creative Commons licences could assist in alleviating such a problem and to avoid what Scassa (2013) has described as the ′Wiki effect – where data are combined from thousands of disparate sources to form one or more coherent works. The perverse outcome may be that the confected data may become more inaccurate, corrupted with further errors and there may be no one to blame because there is no copyright holder or there may be too many owners to be held accountable.

The Australian Copyright Council has proposed several steps to manage and minimise potential liability risks when posting data on websites. These include terms and conditions that state that the host service provider will not infringe copyright. In addition to indemnities, service providers must ensure that the agreements are legally binding. Service providers have also to educate users not to post material without the relevant copyright owner′s consent, to retain the right to remove material if copyright is infringed, to monitor sites for potentially infringing material, and to moderate the process of accepting contributions with a clear statement as to how to complain and how to assert one′s rights.

In cases where the VGI contributed data contain material that infringe copyright whether advertent or otherwise, efforts should be made to remove such material and steps put in place to prevent further infringement. Also the use of disclaimers to alert users to the limitations of the data can help mitigate and prevent litigation.

Other service provider-contributor agreements include the terms of service to be provided by the website, disclosure of information to third parties and data protection protocols including indemnities and warranties regarding the data in storage.

Traditionally geospatial data produced by government agencies have copyright vested in the Crown even in cases where the agency is the first publisher of VGI contributions. In these instances it is important to communicate the intention of the Crown to contributors and to emphasize the terms and conditions of use. In turn, VGI contributors may surrender ownership and use of their data and to limit the extent of the permitted uses.

There may be a binding agreement between the contributors and the websites using the contributed data to ensure that they have not infringed the rights of third parties and that they will indemnify site operators for any damages arising from any such infringements. Such an agreement could include a statement that unequivocally states that the contributors themselves have the rights to the contributed data. On the other hand, contributors may request attribution and acknowledgement of their materials. In most jurisdictions moral rights clauses in the legislation enable the assertion of such rights.

Moral rights, recognised by Australia, Europe and the Berne Convention – droit moral -- protects the integrity of a creator′s works in terms of the right to attribution (claim to ownership of a work), right not to have authorship of a work falsely attributed and a right

to integrity (a right to object to distortion, mutilation or other modification which might be prejudicial to the creator′s honour or reputation).

Ownership issues in terms of the consent to release the data containing private, confidential and sensitive information are also pertinent here. The website may have implicit access to all data found on its servers. However, there is the danger that the data could be disclosed to third parties innocently, advertently, inadvertently by accident, and deliberately by unauthorised persons. The key to such security risks hinge on the contractual relationship between the user and the service provider and how these are managed.

In some cases, there may be jurisdictional prohibitions on the transfer of data across international borders. The EU Data Protection Directive, for example, regulates the processing of personal data within the European Union. Important components of this Directive include privacy and human rights. On 25 January 2012 the European Commission unveiled a draft of the EU General Data Protection Regulation that will supersede the Data Protection Directive which may have direct implications on geospatial cloud computing usage and deployment of crowd-sourced geospatial information on websites.

The potential for the deployment of poor/bad data on VGI sites, misuse of the data, and innocently ′illicit data can lead to a number of potentially unpredictable consequences. Examples of such use of innocent illicit data include the unauthorised use of copyrighted data contributed by a third party data supplier, and the inappropriate use of personal information by VGI user organisations that may contravene privacy and data protection legislation.

There may also be ethical considerations in the release of private information on public documents such as published maps. Scassa (2013) gave the example of Proposition 8 Maps – a mash- up of Google maps and Prop 8 donors to a campaign in support of a ban on gay marriages in California. The map revealed names, addresses and donation amounts of donors. Such revelations were unforseen by the donors and for some who may not have consented to the use of the information in this manner. The potential for mischief, subsequent harm and tort liability as a result of posting of the information could affect the VGI host, contributor and innocent bystander.

A breakdown in contractual relationships and the likely impact of tortious damage from using inaccurate and/or sensitive data point to a discussion of legal liabilities and personal responsibilities that follows next.

Concern #3 Liability: contractual and tortious:

While appearing to be a semantic one, there may be difficulties in determining whether a VGI website is the source of a product, service or mere provision of information. In general, legal liability in common law attaches to negligent behaviour where a duty of care was owed and was breached and where there was a causal link between the negligent act and the loss suffered.

In the case of contributors in the ′crowd who may not have any specialised training or expertise in mapping or geography, mistakes and errors may occur the data collection phase itself. A threshold test for liability is whether there was an exercise of due diligence of a reasonable person engaged in that activity. Liability may be unlikely for an innocent mistake.

Tortious liability may arise in a number of other ways. As a shield against any liability VGI site operators could insist that users accept the terms of use of their data.

VGI data supplier organisations may be liable for negligent contributions of erroneous data that result in injury or damage to persons who have relied on that data. Data accuracy is a critical element that VGI organisations should guard jealously. The extent of the responsibility for user generated content could hinge on the degree of quality control in the data it receives, the editing and filtering of the data, the nature and subject-matter of the data and the degree of control asserted by the data supplier organisation in the data. Under common law tort, the greater the control the greater the responsibility and hence exposure to liability should anything go wrong.

Professional geospatial data producers assume a higher standard of care. They may be sued for providing incorrect data, misleading or negligent information as well as defamatory information. However, it would be difficult to hold amateur contributors to the same standard of care as the collection of their data may not have undergone as rigorous a process as the professionals. Their data may contain minor errors, and may be a synthesis of data from numerous sources.

Another concern with VGI activity is that of the exposure to liability of the volunteer contributor. These volunteers may be described as ′Good Samaritans′. In many jurisdictions, Good Samaritan law is not found on statute books but is a concept adopted by the courts and applied as public policy. However, practices vary in different jurisdictions.

In Australia, the various states have enacted Good Samaritan laws that protect professionals providing assistance at the scene of an accident or any emergency. Most of these provisions define a Good Samaritan (rescuer) as a person acting without expectation of payment or other consideration who comes to the aid of another. Hence, a Good Samaritan should not be liable for assisting in an emergency if all reasonable care and skill has been taken.

However, the laws in much of Europe criminalize a failure to help people in an emergency. Indeed in Germany, the failure to provide first aid to a person in need of help is punishable under § 323c of the German Criminal Penal Code.

In the U.S., courts have taken a view that there is no duty to rescue. Robson′s (2011) discussion of the so-called Good Samaritan laws in the U.S. unequivocally demonstrates that a person is not required to rescue another, even if the person could do so safely. The discussion suggests that:

- A volunteer group that undertakes to rescue others exposes itself to liability.
- A duty to rescue arises only when a person puts another in danger but has a responsibility to mitigate the harm and danger.
- A duty to rescue is required where there exists a special relationship between the parties.

Emergency services using crowd-sourced geospatial information are in an invidious position. The ′Good Samaritan duty of emergency services could be mitigated by not undertaking rescue services and in the case of collecting geospatial data in situ of the emergency, by not providing the crowd- sourced data and maps. It would be ironic to note

that, the digital volunteers could be considered to assume the role of a passive observer and not communicate with the victims. Or, the digital volunteers could discourage reliance on the use of information with disclaimers and other notices with statements to the effect that the information are not to be relied upon in life threatening situations.

Other worries about legal liability, however, remain in the sense that crowd-sourced data might be misused; volunteers could get hurt in collecting the data; the legal responsibility for the data are unascertained and unascertainable; and the legal status of the volunteers themselves, as a loose collective of like-minded people who wish to help, is uncertain. The U.S. Federal statute Volunteer Protection Act of 1997 (VPA) offers some protection to a broader range of volunteers such as operating under organisational structures of a particular kind and imposing limits on volunteer compensation.

In the case of contractual liability – relationship between the VGI website service provider and users – the ′duty is expressed in the ″Terms of Use" posted on the web page. Thus, for contributors, particular care must be exercised by not giving or promising any type of warranty or guarantee for the data submitted. To do so might expose and heighten the risk of legal responsibility for any errors. Contributors could refrain from providing any indemnification for the data and information submitted to the website. From the preliminary findings of the above review, a legal framework may be needed to manage the viewpoints of the three major actors in the piece – the service provider as host, the ′crowd as volunteer contributors, and the disaster manager both as contributor and user.

Current Legal Frameworks and Governance: A preliminary conclusion is that the VGI community in general, and crisis mapping community in particular, may need to develop general standards that address issues of quality, ownership and liability. Each of these issues come about where crowd-sourced maps are deployed whether in a disaster situation or in the calm surrounds of a planning studio. It seems that the consensus is that laws that regulate the use of technology, the governance of volunteered information and protection for all is undoubtedly a looming challenge for policy makers and governments. One view is that if the legal questions are not properly managed, tort liability might have ″the potential to destroy the model before it realises its potential".

Given the need for large-scale data and the ubiquity of geospatial data, technology has been developed to make these available anywhere, anytime and in any way. The Internet and sharing on the cloud and its use for geospatial applications promise a lot but many unresolved legal issues remain.

Since 2010, the Ordnance Survey (OS) GB, the National Mapping Agency in the U.K., has made available geospatial data to the public to encourage innovation and government transparency. OS is by far the largest public sector agency that makes use of cloud computing as part of its web mapping service that deploys geospatial data to customer websites and enterprise systems, services that are hosted on the Amazon Web Services (AWS) platform. Increasingly one platform that is being used to host VGI and crowd-sourced maps is the ′cloud′. Cloud computing provide a means to undertake computing tasks, software, data access, data storage resources. Users of cloud computing (CC) take advantage of computing infrastructure but are not involved in the detailed technical setup.

The advantages, offered by CC generally and to geospatial cloud computing (GCC) in particular, to analysts, users, data providers and others, are unlimited. The benefits include lower costs, provide enlarged access to products and services and be able to do so

online theoretically from anywhere in the world. The need for geospatial software may be leased or paid for on the basis of use and data used acquired on a needs basis through web services. This is indeed neo-geography par excellence and the ′cloud is poised to radically change the way geospatial analytics are performed.

However, geospatial cloud computing raises other concerns such as the security of information and data in terms of unauthorised use of the services, the protection of personal, confidential and sensitive data, intellectual property rights especially of copyright and licensing the use of geospatial data and legal liability. The Natural Resources Canada′s Primer on Cloud Computing discusses a survey that lists ten different security risks. Among these risks include abuse and malicious use of cloud computing by spammers and hackers, weak application programming interfaces (API) that expose cloud computing users to confidentiality and integrity risks, technological vulnerabilities arising from shared technologies, data leakage, service and traffic hijacking, delegations of authority to the vendors and encryption issues.

While the risk concerns appear credible especially with reports of data security lapses, helpful advice is available, for instance, from the European Network and Information Security Agency (ENISA). In addressing some of these concerns an understanding of the roles and responsibilities of both the vendors and users are as important as assessing the threats and mitigating losses. Where these rights and duties have been established, the sharing of liability as well as the burden of the liability may be apportioned by mutual consent through arbitrators and mediators.

The International Bar Association (IBA) has been in the forefront of thinking in attempting to meet the challenges of technological developments. The IBA′s proposed International Geoinformation Convention focuses on the reliability of information for the particular application and the limits the law should seek to impose on the undoubted power of the information. By addressing the many conflicting and overlapping existing rules and regulations associated with the collection and processing of GI, a new industry may develop with commercial certainty about rights and obligations of its many participants and also the confidence in moving in conformity with public opinion. It may be posited that such an industry will not spontaneously blossom without the trellis provided by a robust international legal framework.

Summary and Conclusions: This part has reviewed several concerns with the use of VGI-generated geospatial data. Five conclusions may be made in summary. First, the Web 2.0 environment has witnessed a new wave of data collection methods, data use and data analytics. The challenge is how to manage this new world of geospatial data collection and dissemination. Cloud computing, the Internet of Things (IOT), open standards and open source all challenge traditional means of ′professional data creation, collection and storage. With public sector funding of the collection of geospatial data becoming more restricted in straitened economic times, the public and private geospatial industry may have to turn to use shared crowd-sourced data. Protection by way of licencing and new methods of data ownership will have to be developed. In turn standards and new usage policies may also have to evolve. Yet, there remains tort liabilities related to questions of data assurance, integrity and ownership.

Second, there seems to be an acceptance of the terms of use of VGI data as well as the consequence of the negligent contributions of erroneous data. Also with amateur collectors and contributors of the data, there is an apparent lowering of the standards of care. The use of volunteered and crowd-sourced geospatial databases has highlighted the

tensions with Good Samaritan laws especially for rescuers who may not be shielded legal liability. But the laws are mixed for different jurisdictions from the hard line U.S. position to the more benevolent Australian states. The challenge here for policy makers is that if there were to be no legal protection for volunteers, the ensuing litigation may destroy the VGI model before it reaches its full potential.

Third, cloud computing is the next ′storage media that appeals to the needs of the neo-geography par excellence. Cloud computing is changing the way geospatial information collection and geospatial analytics are undertaken. However, the issues of security of information, the protection of personal, confidential and sensitive data, intellectual property and aspects of tort liability hover in the background.

Fourth, the record and reception of crowd-sourced geospatial data among different jurisdictions is mixed. For example, newly developed countries like China and India, and developing countries like Indonesia are very ′security conscious and sensitive in so far as geospatial information and data are concerned. The fear of threats of invasion and border incursions persist. Indonesia provides an extreme example where all geospatial data are collected by a central agency and no one else may collect such information. The Indonesian Geospatial Information Act No. 4, 2011 provides the legal framework for acquiring accurate geospatial data and creates a regulatory framework for the administration of national geospatial information. Criminal sanctions are attached to deter the collection of geospatial data by private persons.

Fifth, radical changes are needed to reduce geo-liability. This is because legal liability theories governing geospatial information at least in the common law world are largely under-developed and there is a tendency for the law to lag behind technology relative to resolving the growing problems and issues presented by technology and neo-geography. The disparities between legal and policy frameworks are evident.

Technological development in relative terms is without boundaries. Legal and policy frameworks tend to ′lag and are not developed in a consistent manner. Such under-development leads to a degree of uncertainty and perhaps a ′chilling effect on venture capitalists who might refrain from new and innovative investments for ′fear of unknown legal repercussions. On the other hand, addressing the legal and policy challenges head-on may lead to greater developments in geospatial information production and use. A legal framework that provides ′security in all ways could also lead to long-term benefits to those concerned.

Given the three-way interlocking network of interests, the governance of VGI activity can be fiendishly difficult because of the various competing interests and tensions between each of the actors. This preliminary work has only focussed on the legal issues. The difficulties of legal analyses become more apparent in the absence of litigation and/or specific legislation in the field. Yet, the distinctiveness of the problem-set may warrant particular policies to address competing rights and interests and to emerge with solutions to practical problems in the use of geospatial VGI.

The final analysis suggests some kind of a ′relational law is required within a framework where technology, networked governance and legal protection of geospatial information are woven into place. In such a scenario, it would be possible for volunteers to craft a code of practice that can be universally practised. Such a softly-softly self-regulated environment could prove fruitful and more easily acceptable and accepted by like-minded geospatial professionals and by the map using first responder community – the *produsers*.

GeoICT Standards

Introduction: A standard is a reference record endorsed by a perceived institutionalization organization, for example, the Open Geospatial Consortium (OGC) or International Standards Organization (ISO). It characterizes the attributes and voluntary principles pertinent to a set of domain specific activities that requires common processes to address them or deal with them. Standards represent a consensus process among all stakeholders involved with the domain of application. A standard is used to characterize a common role between end users and developers as well as policy-makers and clients involved in specific domain of technology, for example, the OGC standardized Web-based GIS protocols to harmonize policies and procedures involved in product development in the domain. At the same time, standards provide the level of details, quality, security, and environmental impact as well as the value of security. Standards encourage information and product exchange; internationally, it adds to better organizing the economy and encouraging the day-to-day practices of all involved. Institutionalization quickens the development of standards and thus improves the innovation process. A higher level of standardization yields reference systems and results framing a strong premise for and sparing time in the advancement process. At the end-user side, standards encourages the dissemination of creative new thoughts and cutting-edge innovations. They create an environment for mutual communication among involved parties and allow the dissemination of technology.

Adherence to standards guarantees security, unwavering quality, and environ- mental compliance. Therefore, clients see standardized products and services as being more reliable and, as a result, expanding deals and the take-up of new standardized technologies. This part will focus on standardization from different perspectives covering the horizon of GeoICT. It will cover the OOG standards for WebGIS Interoperability as well as the emerging trends in standardization of big data, hydrographic data, and Web standards as well as well as 3D standardization.

Standardization Initiatives: There are many ongoing standardization efforts for GeoICT-related technology. These global initiatives aim at providing support to the geospatial data community to maximize the effectiveness and interoperability among different stakeholders of the geoid technology. In this chapter, three major international initiatives will be highlighted: the Open Geospatial Consortium (OGC), the International Standards Organization (ISO), and the International Hydrographic Organization (IHO). These three institutions provide guidance and direction in developing standards related to geospatial information technology (GeoICT) from a data perspective. There are other initiatives, such as the IEEE and W3 initiatives, which address the technology-related side of interoperability in terms of systems and platforms.

Open Geospatial Consortium (OGC): The information community can be defined as a group of users, both public and private, including public institutions, professional bodies, industry, and NGOs, which permanently or temporarily share common attributes of geographic data and spatial feature definitions including abstractions and world views with all it contains from features and metadata. The OGC is an industry consortium aimed at supporting the development and adoption of interoperability standards for technologies involving spatial information and location. The OGC Consortium aims at creating a world of geospatial information community, in which the common acquisition and sharing of geographic information and services are made available on any network for the benefit of the whole user community whether in the form of applications or platforms. The core

objective of the OGC is to support the creation of spatial interface specifications that are openly available for the wider global user community.

The OGC has shared and applied geospatial information since the early 1980s it is run and managed by management board headed up by a board of directors and an executive director. It represents approximately 500 members of the OGC organization. There are different categories for membership: academia (such as universities and research centers), public institutions, industry, and NGOs. Industry partners in the OGC represent the wide horizon of small-, medium-, and large-sized companies. There are also strategic partners with the OGC who significantly contribute to the mandate of the OGC organization. The OGC has devloped significantly over the last decade to lend more maturity of the specifications and standards that were intiatiated in the past, Fig. 1 shows the current structure of the OGC. There is a complete cycle of standards development that is processed by the board of directors: These are the Strategic Member Advisory Committee and the Global Advisory Council, who offer direction and support of the needed resources for all OGC initiatives whether current activities or mandates of the OGC.

The OGC′s Interoperability Program gives an industry agreement procedure to create, test, illustrate, and advance the use of interfaces and protocols that empower interoperable geoprocessing. The Interoperability Program initiates, develops, and oversees interoperability initiatives that address the accompanying needs of industry and government partners, specifically through the following:

″Plug-and-Play" Geoprocessing: Improvement of the specialized framework for open-distributed and part-based geoprocessing takes place to a great extent in testbeds. Testbeds give a solution to fast-paced, multiseller community-oriented endeavors to characterize, outline, create, and test applicant interface and encoding determinations. These draft details are then examined, updated, and affirmed in the formal OGC specification-adoption process. Sellers execute the particulars in standards-based commercial off-the-shelf (SCOTS) items that are ″open," i.e., interoperable with other merchants items that execute the same interfaces. Collaborating Communities: In pilot projects, client groups working together apply and test the OGC′s interface details in genuine settings using SCOTS products that execute the OGC′s interface and encoding specifications.

Geospatial Integration with Enterprise and Domain Architectures: Through the Interoperability Program, the OGC oversees planning studies, supplement projects, and feasibility studies that help professional bodies outline and actualize venture and space structural engineering arrangements and arrangements that require incorporation and/or interoperability with geospatial data, applications, and services. Outreach and Education: The OGC and its partners are building up a developing arrangement of assets to help innovation designers and clients in the use of OGC implementation specifications and interfaces in their item improvement and obtainment programs. Specialized reports, preparing materials, test suites, reference use, and other interoperability assets created in the OGC′s interoperability initiatives become accessible for use by individuals and/or the general population on the OGC Network.

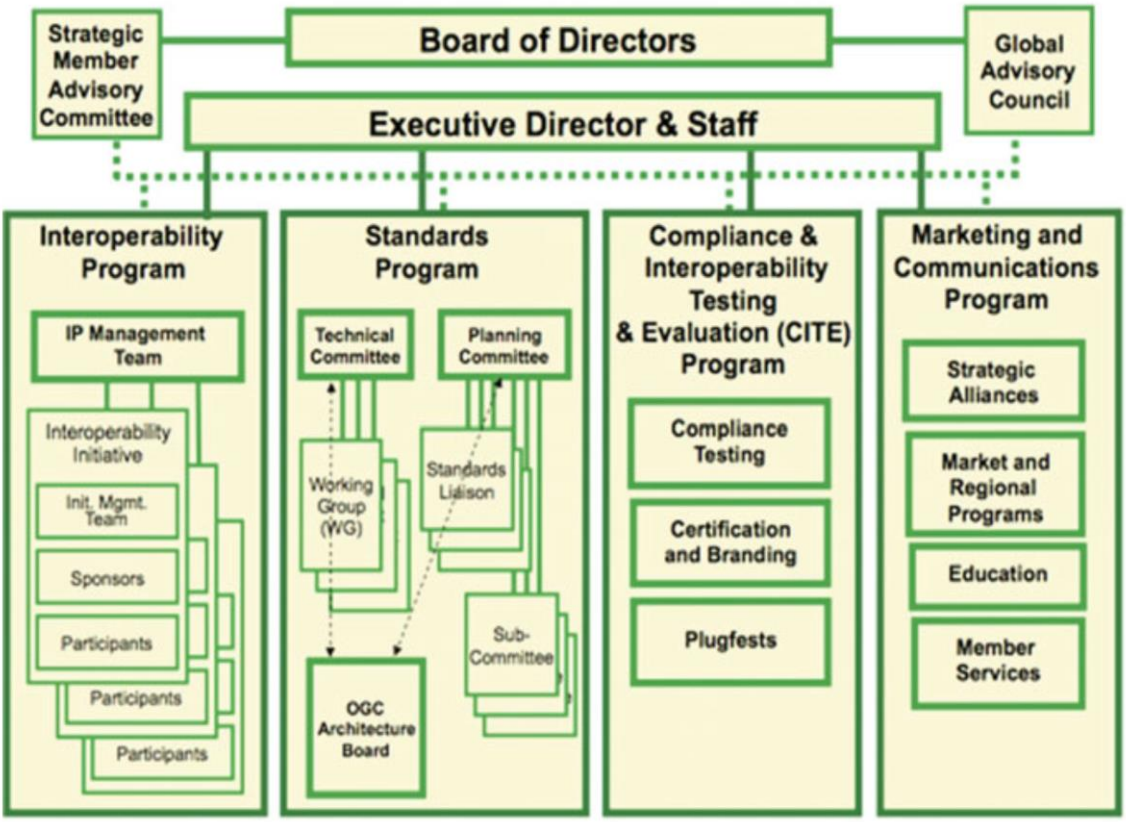


Fig. 1 The structure of the OGC (Courtesy of Open Geospatial Consortium)

OGC Abstract Specification : Abstract specification is composed principally to facilitate knowledge of the real-world spatial phenomena being modeled. Every item in an object class (or feature type) available in the model is clarified in the abstract specification. This incorporates a depiction of the chains of importance and the different connections between them. The objects behavior, role names, and qualities are also clarified. Another part of the OGC abstract specification is to accomplish a common understanding in the consortium about the elements of interest and their behaviors. The OGC guidelines are developed and referenced against the abstract specification; consequently, there is empowering interoperability between diverse brands and various types of spatial handling frameworks. The abstract specification gives a reference model as to the development of OGC standards.

OGC Standards : OGC WEB SERVICES (OWS) are OGC standards provided through Web services. The idea of Web services involves allowing servers to dynamically query, access, process, and combine diverse types of spatial information over the web through OGC specification conformant servers established by other companies and organizations. As yet, OGC has an advanced number of OWS standards as follows:

1. ***Web Map Services (WMS):*** A Web Map Service (WMS) produces maps of spatially referenced information progressively from geographic data. This international standard characterizes a ″map” to be a depiction of geographic information as a digital image file that is suitable for showcase on a PC screen. A map is not the data itself. WMS-created maps are rendered in a pictorial configuration, for example, PNG, GIF, or JPEG or every so often as vector-based graphical components in Scalable Vector Graphics (SVG) or

Web Computer Graphics Metafile (WebCGM) groups. This international standard characterizes three operations: one returns service-level metadata; another returns a map whose geographic and dimensional parameters are characterized all around; and a discretionary third operation returns data about specific components appearing on a map. WMS operations can be invoked through a standard Web browser by demand request as Uniform Resource Locators (URLs). The substance of such URLs relies on which operation is queried. Specifically, while asking for a map the URL shows what data are to appear on the map, what part of the Earth is to be mapped, the suitable coordinate system, and the produced image width and height. Whenever two or more maps are created with the same geographic parameters and output estimate, the outcomes can be precisely overlaid to deliver a composite map. The use of picture arrangements that bolster straightforward foundations (e.g., GIF or PNG) permits basic maps to be noticeable. In addition, individual maps can be requested from different servers. Inn this way the WMS empowers the formation of a system of dispersed map servers from which clients can construct recreated maps. This international standard applies to a WMS occurrence that distributes its capacity to create maps instead of its ability to obtain to particular data possessions.

2. ***Web Coverage Service (WCS):*** The OGC Web Coverage Service (WCS) underpins the electronic retrieval of geospatial information as ″cover- ages,″ that is, advanced geospatial data-communicating space/time-differing phenomena. A WCS gives access to coverage data in structures that are valuable for client-side rendering, as data input into scientific models, and for different clients. The WCS may be contrasted with the OGC Web Feature Service (WFS) and the WMS. As an example of WMS and WFS services, a WCS permits clients to choose segments of a server′s information property taking into account spatial constraints and other query criteria. Unlike WMS, which returns spatial information to be depicted as static maps (rendered as pictures by the server), the Web Coverage Service gives accessible data together with their point-by-point descriptions; it characterizes a rich syntax for requests against these data; and it returns data with its unique semantics (rather than pictures) that can be deciphered, extrapolated, etc., not simply depicted. Unlike WFS, which returns discrete geospatial highlights, the Web Coverage Service returns coverages communicating to space/time-differing phenomena that relate a spatio-temporal area to a (perhaps multidimensional) scope of properties. In that capacity, WCS concentrates on coverages as a particular class of features and, correspondingly, characterizes streamlined utility. WCS 2.0 uses the scope model of the Geography Markup Language (GML) Application Schema for Coverages, which has been produced with the objective that inclusions handled a WCS can be all of the more effectively traded with other OGC administrations. WCS 2.0 backs all scope sorts upheld by said Application Schema; it is not restricted to four-sided framework inclusions like past WCS adaptations.

3. ***Web Feature Service (WFS):*** The OGC WFS allows a client to retrieve and update geospatial data coded in GML from numerous WFSs. The needs for a WFS include (1) the essential interfaces must be well-defined in XML; (2) GML must be used to prompt features within the interface; (3) at the very least, WFS must be capable to present features using GML; (4) the predicate or filter language will be defined in XML and be derived from CQL as defined in the OGC Catalogue Interface Implementation Specification; the data store used to store geographic features should be opaque to client applications and their only view of the data should be through the WFS interface; and (5) there must be use of a subset of XPath expressions for referencing properties.

4. ***Web Processing Services (WPS):*** The OGC Web Processing Service (WPS) interface standard provides a typical interchange that streamlines the duty involving the generation of uncomplicated or composite computational processing services that can be accessed through World Wide Web services. These kinds of services include recognized methods obtained in the GIS soft- ware package in addition to specific operations pertaining to spatio-temporal modeling, visualization, and simulation. Although the OGC WPS standard was developed with a vision to incorporate spatial-processing capabilities through the Internet, the addition of commonly used nonspatial data processing over the World Wide Web was also emphasized. The WPS standard typically provides a vigorous, interoperable, and multipurpose protocol for execution on Web services. It can handle instant processing pertaining to time-consuming computational jobs as well as asynchronous digesting for far more superior as well as complex time-intensive tasks. The WPS standard explains a general course-of-action model that is meant to offer an interoperable description involving processing tasks. It is envisioned to support process cataloging as well as discovery in a distributed environment.

5. ***Catalogue Service for the Web (CS-W):*** The term ″catalog" is needed to go into detail about the original service interfaces that supports organizing, discovery, and access of geospatial information associated with geospatial details. Catalog services help end-users or application software packages to discover information that exists within a distributed computing setting. The catalog is usually realized as a dedicated database associated with details about geospatial properties that are accessible to a community of operators. These resources are required to obtain the OGC feature, feature allocation, catalog, as well as metadata interfaces, or maybe they might be geoprocessing services.

6. ***Styled Layer Descriptor (SLD):*** The layered descriptor specifies how a WMS could be worked out to allow user-defined tailoring. Unique modalities associated with applying symbology development for this reason can be obtained. The value of the aesthetic portrayal associated with geographic data cannot be overstated in the SLD. The proficiency that adopts portraying geospatial facts, no matter whether it is geographic features or attribute tables, is recognized as seeing what exactly turns location facts directly into an explanatory or decision-support tool. The current OGC WMS standards convention has this ability on an information supplier to identify elementary styling options through marketing of your existing pool associated with visual portrayals for each and every accessible data set. Nevertheless, although a WMS presently can provide the end-user with an option of the many design possibilities, the WMS might provide the end-user with a tag of the design. It cannot guide the user to what the portrayal will look like on the map.

More significantly, there is no option for the user to distinguish their styling policies. The ability for human or machine clients to summarize these kinds of policies requires a styling language that the client, as well as server, can similarly identify. Outlining this specific language is called ″symbology encoding" (SE), which is performed in a supporting supplementary document of this specification. This language enables the user to employ the output of Web Map Servers, Web Feature Servers, and Web Coverage Servers. There are two direct solutions to for styling a data set. The first is to direct color all features together.

For example, one can visualize a layer advertised by WMS named as ″land cover" composed of lines and polygons that represent specific roads and farms on the map. Some users may want to instruct the server to color the interiors off polygons in a very light

glowing green color to represent farms and to color the limitations of polygons as well as all lines representing roads in black. This type of styling involves no information about the attributes or ″feature types” of the original data. Specific language is used here to provide information about these styles, which usually requires going into detail with these kinds of models. This requirement is resolved from by the Feature Type Style element in the SE document.

7. ***Web Map Tile Service (WMTS):*** The Web Map Tile Service (WMTS) Implementation Standard delivers a standard-based explanation to serve digital maps using predefined image tiles. The service promotes the titles it has available for a consistent declaration in the ServiceMetadata file common to all OWS. This declaration describes the tiles obtainable in each layer (i.e., each type of content), in each graphical demonstration style, in each format, in each reference coordinate system, at each scale, and over each geographic portion of the total enclosed area. The ServiceMetadata document also states the communica- tion protocols and encodings over which clients can interact with the server. Clients can read the ServiceMetadata file to request exact titles. The WMTS standard supplements the existing WMS standard of the OGC. The WMS standard emphasizes flexibility in the client request, thus allowing clients to obtain exactly the image they want. A WMS client can demand that the server make a map by covering a subjective number of the map layers obtainable by the server, over an arbitrary geographic bound, with a random related color on an arbitrary scale, in any supported coordinate reference system. The client can similarly demand that the map layers be extracted by means of a specific server-promoted style or even use a style as long as the client based on the WMS server implements the OGC Styled Layers Descriptor (SLD) standard. Nevertheless, all of this flexibility comes at a price: Server image processing essentially scales with the number of linked clients, and there is only partial potential to cache images between the server and client due to the great diversity of images.

This standard specifies WMTS in dual phases. First, an abstract specification labels the semantics of the resources accessible by the servers and demanded by the client. This abstract description stipulates the semantics of the ServiceMetadata document, the tile images or symbols, and the elective FeatureInfo files providing descriptions of the maps at precise locations. Second, this standard requires numerous diverse concrete exchange mechanisms between clients and servers in two altered architectural styles.

Other OGC Standards

These standards are not dependent on the Web for execution, i.e., not related directly to the concept of OWS.

1. ***Keyhole Markup Language (KML):*** Google developed KML, and it was adopted by the OCG as a data standard. It encodes what is to be shown in an Earth browser and how to show it. KML uses a tag-based structure with nested elements and attributes and is based on the XML standard. KML is a form of XML grammar used to encode and transport representations of geographic data for display in an Earth browser, such as a 3D virtual globe, 2D Web browser application, or 2D mobile application. A KML instance is processed in much the same way that Web browsers process HTML (and XML) documents. Like HTML, KML has a tag-based structure with names and attributes used for specific display purposes. KML can be used to do the following: annotate the Earth, specify icons and labels to identify locations on the surface of the planet, create different camera positions to define unique views for KML features, define image overlays to attach to the ground or screen, define styles to specify KML feature appearance, write

HTML descriptions of KML features including hyperlinks and embedded images, organize KML features into hierarchies, locate and update retrieved KML documents from local or remote network locations, AND Define the location and orientation of textured 3D objects.

2. ***Geographic Markup Language (GML):*** Geography Markup Language (GML) is a form of XML encoding for the transport and capacity of geographic data including the geometry and properties of geographic components. Similarly with the OGC Simple Feature Specification, GML uses the OGC Abstract Specification geometry model. In contrast, unlike the Simple Features Specification, the GML specification incorporates the capacity to handle complex properties. The GML was intended to do the following:

- give a method for encoding spatial data for both information transport and information stockpiling, particularly in a wide-region Internet connection;
- be adequately extensible to bolster a wide assortment of spatial errands from depiction to examination;
- set up the establishment for an Internet GIS in an incremental and secluded style;
- take into consideration the productive encoding of geospatial geometry (e.g., data compression);
- give straightforward encodings of spatial data and spatial connections including those characterized by the OGC Simple Features model;
- have the capacity to separate spatial and nonspatial substance from information presentation;
- license the smooth incorporation of spatial and nonspatial information, particularly for cases in which the nonspatial information is XML-encoded;
- be ready to interface promptly spatial (geometric) components to other spatial or nonspatial components; and
- provide an arrangement of basic geographic display items to empower interoperability of freely created applications.

GML is situated as an open-information trade standard appropriate for transmitting small- to medium-sized volumes of data. GML is usable with all standard XML devices. Of specific note are the apparatuses intended to channel XML (XSL) and to transform XML into a visual presentation (XSLT). Using the XSL instruments, a completely useful GML database can be distributed into more restricted variants. For instance, to fulfill administrative prerequisites, a subset of the information, maybe with lower constancy, can be consequently separated. The information can first be separated and balanced on the premise of what the supplier needs to know.

3. ***Sensor Model Language (SensorML):*** The essential purpose of SensorML is to give a system to characterizing procedures and preparing segments connected with the measurement and post-measurement change of information. In this way, SensorML places more emphasis on the procedure of measurement and observation as opposed to sensor hardware, yet it still gives a vigorous method for characterizing the physical qualities and functional capacities of physical procedures, for example, sensors and actuators. The themes of SensorML are as follows:

- provide representations of sensors and sensor frameworks for inventory management;
- provide sensor and procedure data in the backing of benefit and support of asset and observation discovery;
- support processing and analysis of the sensor observations;

- support the geolocation of observed values (measured data);
- Provide execution and general description of attributes (e.g., accuracy and limits);
- Provide general portrayals of parts (e.g., a specific model or type of sensor) as well as the particular setup of that segment when it is conveyed;
- provide a machine-interpretable portrayal of the interfaces and information streams streaming all through a segment;
- provide an unequivocal depiction of the procedure by which a measurement was acquired; and
- provide a total executable strategy for determining new data products of interest (i.e.,, resultant items).

SensorML gives a common framework to many procedures and is especially appropriate for the portrayal of sensor and frameworks and the procedures encompassing sensor measurements.
Inside SensorML, sensor and transducer segments (detectors, transmitters, actuators, and filters) are all shown as physical procedures that can be joined and partaken apart equally inside of a procedure system or framework and that use the same model structure as with all other procedures.

The models and schema inside of the center SensorML detail give a ″skeletal" structure for depicting processes and sensor frameworks. Interoperability within and between different sensors groups is extraordinarily enhanced by the meaning of shared-group particular semantics (inside online ontologies) that can be used inside of the structure. Likewise, it includes the profiling of small, general-use, and centralized procedures that can serve as segments inside of aggregate procedures and frameworks.

4. ***Location Service (OpenLS):*** This also known as the GeoMobility Server (GMS), which is an open platform for location-based application services. This service brings subscribers the convenience of an online directory to discover adjacent or specific places, products, or services. Through an appropriately prepared OpenLS application, the subscriber begins to express the exploration factors in the service request and find the location, product, or service they pursue by entering the name, type, category, keyword, phone number, or any other ″user-friendly" identifier. A location must also be accompanied in the request when the subscriber is looking for the adjacent location, product or service or if they require a place, product, or service at a particular location or within a particular area. The position can be the present ″mobile terminal location," as specified by the gateway service, or a remote location recognized by some other means. The directory type might also be identified. With the expressed request specified, the directory service examines the suitable online directory to fulfill the request and finds the adjacent or specific place, product, or service based on the search criteria. The service receives one or more reactions to the query where the responses are categorized in sequence based on the query criteria. There are two basic ways to determine a specific point of interest that inaccurately corresponds to the pinpoint and proximity requests: (1) by some assets of the point of interest (e.g., unique identifier, name, description, phone number, absolute location); and (2) by its position in terms of some other point of interest (e.g., nearest to me, within some distance of a specified entity, within some defined boundary).

5. ***Open GeoSMS:*** Short Message Service (SMS) is the content correspondence administration part of telephone, Web. or portable correspondence frameworks. SMS uses

institutionalized interchange conventions that permit the trading of short instant messages between settled line or cell telephone gadgets. The capacity of the OGC Open GeoSMS encoding standard is to encourage correspondence of area substance using the broadened SMS highlight between diverse LBS (location-based service) gadgets or applications for accomplishing interoperable interchanges while retaining human comprehensibility of the substance. To be specific, any application or service can essentially influence an expanded SMS message using the Open GeoSMS group. This standard expects that SMS is the most widely recognized correspondence system between cellular telephones and PNDs (personal navigation devices). By using SMS, this stan- dard uses a current, broadly upheld transportation convention and conveyance encoding. The Open GeoSMS standard characterizes a developed organization of the SMS with basic area content for accomplishing interoperable interchanges while maintaining human comprehensibility of the substance. Any application or service can essentially send an augmented SMS message using the Open GeoSMS position. The target client device receives this area-empowered SMS message and afterward can further process the content of the message, for example, for a map display. No additional equipment or infrastructure is required for executing this standard.

6. ***GeoAPI:*** The GeoAPI library contains a progression of interfaces and classes in Java language characterized in a few bundles that translate into Java the information model and Unified Modeling Language (UML) types of the ISO and OGC standards documents. The library incorporates broad Javadoc code documentation, which supplements the directives of the ISO/OGC details by clarifying particularities of the GeoAPI library, e.g., clarifications made to the standard where there was space for choice, limitations because of the library′s use of Java, or standard examples of conduct expected by the library. The standard does not yet propose a complete arrangement of interfaces covering the whole conceptual standard of the ISO/OGC and concentrates on a beginning gathering of interfaces only. This introductory gathering of interfaces covers enough of the theoretical model to allow the meaning of a geospatial coordinate system and geodetic anchoring points focuses as well as empower the change of coordinate tuples between distinctive reference systems.

Emerging Trends in GeoICT Standardization

The ISO Standardization Efforts for Big Data: The ISO is an autonomous, nonlegislative participation organization. It contains 62 member states and works with numerous with many organizations to develop standards. Recently, a report about ″big data" was produced by the IHO that touches on this imperative development identified with geospatial innovation. The report presents tremendous information about the term ″big data" and the importance that has arisen to depict another concept for data applications. New innovations have a tendency to develop with numerous applications and demands; however, some time can be set aside to tell what is new and diverse. Although big data has been characterized in many ways, the heart of the big- data concept is that it is too huge (volume), arrives too fast (velocity), changes too rapidly (variability), contains an excessive amount of commotion (veracity), or is excessively assorted (assortment) to be handled inside of a local computing processing structure using conventional methodologies and systems.

The advances being made in terms of backing this concept have an extensive variety of interfaces, thus making it difficult to develop tools and applications that incorporate information from different big-data sources. Big data are characterized similar to data sets

with qualities (e.g., volume, speed, assortment, variability, and veracity), i.e., a specific field of application domain, at a given point in time, cannot be proficiently prepared using current existing conventional technologies and strategies so as to deal with these data.

The term ″big data” is used as a concept that refers to the inability of conventional data and system architectures to effectively handle the new data sets. Attributes processing brings another challenge to the design and to accomplish efficiencies the data sets are, due to varying characteristics, represented by the volume, and an assortment of information from various domains or sorts; and from the continuous attributes data production in velocity, or rate of flow, and variability. Each of these elements results in distinctive architectures or diverse data life-cycle process orderings to accomplish the required efficiencies. Some different terms (frequently beginning with the letter ″V”) are also used; however, these relate mostly to the analytics side rather than the diversity of data architectures.

The new big-data paradigm occurs when the size of the monolithic system with vertical scaling or dynamic data requires the information service to be a huge driver in the underlying framework. In a general sense, the big-data concept speaks to a movement in spatial data architectures from solid frameworks with vertical scaling (speedier processors) into a horizontally scaled architecture that incorporates an approximately coupled arrangement of assets. This movement happened approximately 20 years ago in the simulation community when the logical recreations started using massive parallel-processing (MPP) systems. In transmitting diverse blends of part code and part information cross-wise over free processors, computational researchers were able to extend their simulation capabilities significantly. This obviously presented new challenges in some application areas such as message passing, data movement, latency in the consistency across resources, load balance, and system inefficiencies while waiting for different system-processing elements to finish their data-processing tasks. In the same way, the big-data paradigm represents this same shift, again using diverse systems to circulate code and data across loosely coupled resources to give scaling in data handling that is expected to coordinate the scaling of the data.

The IHO Standardization Efforts for Hydrographic Data : The IHO Hydrographic Geospatial Standard for Marine Data and Information includes 12 related parts that give the user a suitable system and tool to create and maintain hydrographic-related information, items, and registers. For hydrographic and related data, these standards indicate strategies and instruments for data man- agement, processing, analysis, accessing, presenting, and transferring such data in an advanced/electronic structure between distinctive users, systems, and locations. By adopting the prescribed set of hydrographic geospatial standards, the users will have the capacity to build the essential parts of the most common standard for nautical charts known as S-100 and compliant products. S-100 accommodates as similarly as possible the ISO TC 211 series for geospatial information standards; where important has been custom made to suit hydrographic requirements. S-100 details the standard to be used for the exchange of hydrographic and related geospatial data between national hydrographic offices and between different orga- nization as well as its transference to chart makers, mariners, and other data users. S-100 involves numerous parts that profile principles created by the ISO Technical Committee 211. ISO TC 211 handles the ISO standards for geographic information. The goal is that, together, the standards will shape a system for the advancement of particular applications that use geographic data. S-100 is a sample of such a solicitation. This standard indicates the methodology to be taken after for (1)

building up and maintaining registers of hydrographic and related information; (2) creating product specifications, feature catalogues, and a definition of a general-features model; (3) using spatial, imagery and gridded data, and metadata particularly for satisfying hydrographic requirements.

Standards should typify the use of best-practice systems and strategies. They ought to incorporate direction on the most proficient method with which to execute effective generation strategies and upgrade the nature of an organization′s products and services. They should additionally empower interoperability between different technologies through the use of regular interfaces. The S-100 standard endeavors to accomplish these goals. Moreover, it gives a framework that can be used by intrigued groups to build up their marine geospatial products and services. The S-100 standard was written with the benefit of insight into the past in terms of experience gained through the improvement and use of the current IHO Transfer Standard for Digital Hydrographic Data (known as S-57). S-100 has been recorded using an object-oriented documentation framework known as Unified Modeling Language (UML).

The S-100 standard provides a hypothetical construction of parts based on the ISO 19100 standards and specifications. These principles and particulars are like- wise used as the premise for the advancement exercises of the most contemporary geospatial models and are firmly adjusted the improvement activities of different standards, for example, the OGC. The IHO has likewise built up a related registry, which can be used in conjunction with the S-100 standard. The IHO Registry contains the accompanying extra segments as follows: Feature Concept Dictionary (FCD) Registers, Portrayal Registers, and registers of IHO maker codes. The IHO registry gives the foundation and mechanisms required to oversee and maintain the resources mentioned previously and to broaden them as necessary.

The IEEE Standardization Efforts for Networks and Hardware Technology: The IEEE Standards Association (IEEE-SA) is a standardization body for tech- nology and telecommunication innovations and protocols. Through 20 different working groups, the IEEE-SA provides standards in aerospace electronics, antennas and propagation, batteries, communications, computer technology, consumer electronics, electromagnetic compatibility, green and clean technology, healthcare IT, industry applications, instrumentation and measurement, nanotechnology, national electrical safety code, nuclear power, power and energy, power electronics, smart grid, software and systems engineering, transportation, and wired and wire- less. All of these groups are in close connection to GeoICT.

The standard development cycle in the IEEE-SA has five distinct phases: (1) initiating the project, (2) mobilizing the working group, (3) developing a standard, (4) balloting the standard, and (5) gaining final approval of the standard.

The last stage in standard development is maintaining the standard through regular evaluation according to the technological developments in the field. IEEE-SA works in close coordination with other GeoICT standards associations mentioned in this part.

W2 and W3 Standardization Efforts on Web Services : The World Wide Web Consortium (W3C) creates an open Web platform for application over the Web. The W3C standard characterizes an open Web platform for application improvement that has exceptional potential to empower engineers to construct rich intuitive encounters, controlled by limitless data stores that are accessible on any device. W3C is concentrating

on advancements to empower the Web to be accessed at any place and at whatever time using any device. This includes Web access from cellular telephones and other cell phones as well as the use of Web innovation in gadgets, printers, intuitive TV, and even cars. W3C inspires interaction and mixing by means of worldwide Web standards. These standards guarantee that the impractical will be avoided, and it keeps on enhancing the fact that Web can be accessed any user community. The Web′s value and development rely on its all-inclusiveness. Standards ought to have the capacity to be shared through the PC we have, the language we talk, whether we are wired or remote, paying little respect to our tactile or cooperation modes. We ought to have the capacity to access the web from any equipment that can access the Internet whether it is stationary or portable, small or substantially large.

Web design and applications include the norms for building and rendering Web pages including HTML, CSS, SVG, Ajax, and different advances for web applications (″Web apps"). This segment additionally incorporates data on the best way to make pages open to individuals with incapacities (WCAG), internationalize them, and make them take a shot at cell phones. W3C builds up these specialized particulars and rules through a procedure intended to augment agreement about the substance of a specialized report, to guarantee high specialized and publication quality, and to gain underwriting by W3C and the wider community.

Web architecture concentrates on the establishment of advancements and standards, which include maintaining the Web including URIs and HTTP. Notwithstanding the excellent ″Web of archives" that W3C is building, there air an innovation stack to bolster a ″Web of information," i.e., the kind of information that is found in databases. A definitive objective of the Web of information is to empower PCs to accomplish more helpful work and to create frameworks that can back trusted organizations over the system. The phrase ″Web of services" alludes to the message-construct plan often found in light of the Web and in big-business programming. The Web of services depends on advancements such as HTTP, XML, SOAP, WSDL, SPARQL, and others.

Despite the fact that the limits of the boundaries on technology continues to evolve, industry inventors talk almost as one about how HTML5 will be the foundation of this platform. In any case, the full quality of the stage depends on numerous innovations other than those W3C and its associates are creating including CSS, SVG, WOFF, the Semantic Web stack, XML, and an assortment of APIs. The term ″Semantic Web" alludes to W3C′s vision of the Web of connected information. The Semantic Web empowers individuals to make information stores on the Web, construct vocabularies, and compose rules for dealing with information. Connected information is enabled by such advances as RDF, SPARQL, OWL, and SKOS.

Web 3D Standardization Efforts : The Web3D Consortium is an international, nonprofit, member-funded, industry standards-development organization. The Web3D Consortium is making efforts to provide the X3D standard, which is a royalty-free, open standard for file-format specification to represent and communicate 3D objects, events, and environments. The Web 3D Consortium works in close coordination with the ISO, the OGC, and the W3C.

The Extensible 3D (X3D), rectified by the ISO, is managed by the Web3D Consortium. This standard supports web sharing of interactive 3D graphics between various applications through different distributed networks and Web services. It allows

applications communication over the Web using an ISO standard Scene graph model. It can be encoded in XML, VRML Classic, and binary code. It is accessible from multiple languages, as well being modular and extensible, which provide further additional time for developers. The X3D is open and free for use without licensing restrictions. It allows for a common fabric-based development between various developers and tool makers through common authoring pathways. Many applications can support the X3D content, and it is being used for cross-platform interactive deployment of shared virtual environments from wide-screen CAVEs to small tablets.

The X3D provides rich components that are employable by many users that provide virtual-reality and augmented-reality modeling and simulation as well as advanced visualization on normal personal computers and handheld devices. The X3D standard provides a real-time innovative 3D solution that continues to develop as a technology and as a user community. It is very supportive of various GeoICT technologies and can be used without restrictions or limitations.

Summary : The world is moving to a more standardized GeoICT technology. Web services, databases, and Internet standards are progressing rapidly. They key characteristic is that geoprocessing is moving out of the ″backwater″ and into the more distributed and standardized information technology (IT). Segregated, stand-alone frameworks are being supplanted by coordinated segments, and substantial applications are being supplanted by smaller, more flexible applications that cooperate candidly crosswise over systems. The World Wide Web is turning by and large into the center medium for disseminated registering in IT and the geoprocessing domain.

New spatial information systems are coming each day globally to the Web. The contribution of IT improvement or performs the prerequisite designing. Converse with individuals in wards that are moving toward more interoperability, in order to obtain more data from different providers and integrators who have propelled interoperability in the OGC, and have them show how today′s interoperable arrangements offer advantages that were until now simply imagined.

The development of common GeoICT standards are emerging to the point that they harmonize together efforts in the different fields of this science to provide a complete efficient solution for not just a local user but also a global user who can access, visualize, analyze, and process data from any place at any time at no or minimal cost.

MODULE-V

GIS IN INDIA

MODULE-V: GIS IN INDIA

Geospatial Policies in India and Their Implementation in Good Governance

Introduction: During the First Five-Year Plan of the government, a S&T policy was announced in 1956 to give the boost of science, technology, application and development. Also, the government has opened various opportunities under various themes to promote multiple sectors towards the vision of inclusive growth in science. In the process, number of new institutions and academic institutions were set up to work exclusively in different areas. One of the important institutions, i.e. Survey of India was already in existence. The basic job of the Survey of India (SoI) was assigned to survey topographic maps on 1:50 K scale for the entire country. SoI has collected topographical details during 1965–1970 and finally printed the maps in 1980 for the use of different purposes by the government as well as by the general public. In order to distribute such maps, there was a policy under which topographical sheets were made available to the public with the written request.

With the advancement of satellite technology and also Indian capability in this area made possible to acquire large amount of topographical information by the satellite images and upscale the maps quickly. With this advancement, the availability of geospatial maps and data accessibility become easier and faster. In addition, there are number of other agencies in government like Geological Survey India (GSI), Forest Survey of India (FSI), National Informatics Centre (NIC), Directorate of Census and Ministry of Statistical and Programme Implementation have also collected huge data sets (spatial and non-spatial). In order to handle and use such voluminous data for various applications, the need was felt at different levels to draw the policies to address various issues related to the data quality, standards, usage, security and civil applications. In this series, the following policies were announced by various departments of the government.

Existing Policies Dealing Geospatial and Non-spatial Data

Open availability of satellite data and digital forms of maps, especially when seen in the global context, has necessitated policymaking in India, over the last two decades, such as:

- ***National Map Policy (NMP), 2005***: It basically defines the scope, distribution and liberalised access of digital survey of India topographic maps to user groups without jeopardising national security. As per this policy, SOI has prepared open series topographical maps for the use of the civil purposes which were made available as per the policy.

- ***The Civil Aviation Requirement (CAR), 2012***: This policy basically details procedures for issuance of flight clearances for agencies undertaking aerial photography, geophysical surveys and cloud seeding.

- ***The Remote Sensing Data Policy (RSDP), 2011***: It defines the distribution pro- cess of satellite images to different category of users and their availability for attending various applications.

- ***The National Data Sharing and Accessibility Policy (NDSAP), 2012***: This pol- icy basically deals with providing an enabling provision and platform for proactive and open access to data generated through public funds available with various departments and organisations of Government of India. The Policy at present has made considerable progress to enrol about 106 Government departments to proactively sharing the data on

the national portal, i.e. data.gov.in. Further efforts are on to enrol State Government agencies to adopt this policy and share their data for public use.

- ***National Geospatial Policy (NGP):*** This policy is being coordinated by Department of Science and Technology and is at the drafting stage. Once, this policy is ready, it will empower people to access geospatial data for addressing their need using geospatial technologies without compromising national security. Also, it will play a vital interface between government and other agencies for doing ease of business.

Standards, Spatial Framework and Technologies: Open Geospatial Consortium (OGC) standards are immensely popular and adopted by government and industry and bring about a high level of focus on interoperability through open standards. OGC standards have been defined to systematise metadata, map services and Web services and host of applications services. The following key parameters are defined for standards development:

- Content standards
- Metadata standards
- Schema/data models
- Spatial framework
- Quality
- Image
- GIS services
- Portal standards.

In India, Department of Space has published NNRMS standards, 2005. Thereafter NSDI standards which were limited to metadata and SOI data exchange. Under Ministry of Urban Development, the national urban information system programme is initiated in 2004–06, adopted from NNMRS standards. As a part of this, 153 towns have been completed and verified.

Advancement in Technology for Data Acquisition : World over, satellite images have reached sub-meter accuracy levels operationally and with unprecedented coverage. As our capacity to handle massive spatial data sets grows, with higher bandwidth of networks, newer applications have evolved. Many more such applications that harness evolving technologies and standards need to be developed in various sectors like infrastructure development, agriculture and water resources, disaster management, land use and land management, developing state spatial data infrastructure for attending area specific problems using high resolution and accurate satellite images. This has made tremendous impact in the use of geospatial data and developing area specific problems. In the light of this, all the geospatial policies listed above have some component of supporting the technologies and applications and promoting and adopting to solve micro-level planning for good governance.

Other Advanced Technologies for Data Acquisition : In addition to the satellite images available in various resolutions and accuracy, the technologies unmanned vehicle, drone mapping and global positioning system (GPS)/ground penetrating radar (GPR) have made significant headway for data acquisition of high standard accuracy. For example, unmanned ariel vehicle (UAV) is of high potential and useful to support rapid mapping activities in terms of accuracy and flexibility. Its high resolution can be turned into proper higher accuracy by means of integration with existing geospatial data, i.e. airborne IFSAR data to map the disaster area immediately. In a similar light, unmanned surface

vehicles (USVs) are useful in bathymetric surveys of reservoirs and other water bodies, towards creating data sets to help water resource planning or flood mitigation. Therefore, conventional data available with various departments are considered not so much important due to the availability of such data sets. Therefore, all the data sharing policies should be facilitating the use and accessibility of geospatial data to the common person and its benefit to the society.

Future Scope of Geospatial Data and Policies : At present, the advancement in the development of sensors and resolution of data capturing and accuracy has made significant progress. Considering this in view, the development of infrastructure to deal such data set and attend application needs high level of expertise and computational facility which needs to be developed at various levels including institutional as well as operational level. The only issue remaining is the operationalization of geospatial data and its usage at various hierarchical level, i.e. state, district and subdistrict level. The geospatial technology for good governance at the micro level needs to be promoted to accrue maximum benefit.

National Spatial Data Infrastructure India (NSDI-India)—Present Status and the Future Strategies

Background : India has been at the threshold of a major transformation with the adoption of a series of reforms by the government and with a positive future prospect for all-round development. Priorities of the government have been set on ′Ease of Living or Doing Business′, ′Inclusive Growth and ′Good Governance to ensure economic prosperity, environmental preservation and social welfare. Effective implementation of these priorities requires a sound integrated framework covering issues from all sectors of economy, environment and society for decision-making and governance. In order to remain sustainable, there is a need for making governance and decision- making processes more transparent and people-oriented while taking into account the local (district or subdistrict) natural resource endowment and needs. Drawing up such integrated strategies being complex and information-intensive requires utilization of various geospatial data and technologies at different levels of the planning and governance hierarchy. Use of geospatial data and technologies is essential for making sound decisions and preparing implementation plans along scientific lines towards successful delivery of benefits of various programmes and schemes. In support of implementation of these schemes and programmes, activities of various ministries/departments of the government and the states have been reoriented towards their use besides improving user′s accessibility to and application of digital geospatial data sets and processes that provide the required underpinnings to decision-making.

In spite of the above, there have been several problems encountered by the end-user agencies in effective utilization of geospatial databases and technologies. Non-availability of data sets of right resolution and currency; inaccessibility to databases over the Web/Internet/mobile devices; lack of standardization and interoperability; inability of organizations in making their data sets amenable to quick retrieval, update and analysis; nonavailability of a sound technology platform (hardware, software, connectivity, decision support module, etc.) for collaborative map-making and processing; inadequate integration or alignment of geospatial (Geo-ICT) processes with workflows of end-user organizations/agencies; and inadequate capacity amongst the end-users have been the major bottlenecks. There is thus a need for developing and making accessible geospatial

databases and requisite applications/products at national, state and local levels to support governance and decision-making.

Taking note of the requirement of the stakeholders like the government, private enterprises, academia; and the civil society organizations, National Spatial Data Infrastructure (NSDI) initiative has been jointly launched by Department of Science and Technology (DST) and Department of Space (DOS). Various agencies concerned with provision and consumption of geospatial data sets in the central and state governments have been developing geospatial databases and redesigning their geospatial data management processes for improving data sharing over the Web in the framework of the National Spatial Data Infrastructure (NSDI).

Introduction : To facilitate data sharing over the Web in SDI framework, various agencies have been adopting international spatial data and process standards from Open Geospatial Consortium (OGC); and International Standardization Organization (ISO). Interoperable spatial data services based on standards have been operationalized by the respective organizational data nodes/portals of various agencies for providing access to data services for automated access by applications/software utilities. Metadata (data about data) of the geospatial data sets to facilitate search and discovery of maps and data have been made accessible from the NSDI portal. At the state level, State Spatial Data Infrastructures (SSDIs) are being set up in collaborative mode between DST and the state governments for providing access to various geospatial data sets relevant to state′s jurisdiction, e.g. cadastral plot boundaries, land ownership, groundwater, mining and geology.

Related Policies : With the launch of NSDI, efforts have been made to relax the restrictive policy regime. In 2005, the National Map Policy has been approved by the Union Cabinet providing for the preparation of Open Series Maps (OSM) for civilian use and Defence Series Maps (DSM) for exclusive use by the defence forces. NSDI initiative has been formally launched through a cabinet resolution in June 2006 with the objectives of improving access to organized collection of geospatial data, making those searchable and discoverable through their metadata and sensitizing end-users on the benefits of NSDI. A two-tier coordinating structure as indicated in later part of this section, with more details has been installed to facilitate standardization and interoperable sharing of geospatial data amongst the stakeholder agencies. A single window access mechanism of India geoportal has been made operational for providing access to metadata of various agencies.

In order to facilitate sharing of data sets and improving accessibility, a National Data Sharing and Accessibility Policy (NDSAP) has been notified by the government in February 2012. As per the provisions of the NDSAP, the National Open Government Data Portal (data.gov.in) has been implemented by the National Informatics Centre (NIC), New Delhi. A National Remote Sensing Data Policy has been framed in May 2011 to govern sharing of and access to satellite data sets and images in the country. The Information Technology (IT) Act, 2000 of Ministry of Electronics and Information Technology (MeitY); the Right to Information (RTI) Act, 2005 of Department of Personnel & Training (DoPT); and various state-level data sharing and Accessibility Policies have been framed by various states to improve sharing and accessibility. Despite availability of the above policy framework, it has not been possible to search/discover geospatial data sets in an easy and user-friendly way; quickly interpret analysed results and use them in decision-making process; and seamlessly link data sets from various

sources/agencies. As a part of the implementation of the NDSAP, Open Government Data Portal has been operationalized for providing open access to government data sets.

Towards overcoming the above problems, it has been decided to frame a more comprehensive National Geospatial Policy (NGP) covering geospatial data, products, services and applications. Formulation of a National Topographic Frame and a National Image Frame covering the National Foundation Spatial Data Sets, formation of a National Geospatial Authority (NGA); and user-friendly sharing of geospatial data sets for easy accessibility by various stakeholders have been envisaged in the proposed Policy.

Databases, Metadata and Architecture : Over the past years, efforts have been made by NSDI to compile and serve metadata of different partnering agencies and reengineer the feature data sets for improving their use. The NSDI partnering agencies have large amounts of feature data sets/images and are presently managed in file-based systems largely through quadrangle sheets/scenes without appropriate strategies for fully automated search, querying and processing. This is evidenced in the present ways to store and manage metadata sets as per the indices of quadrangle sheets/scenes of data providing organizations. Identification and maintenance of feature data sets, in particular, thus pose a major challenge to the stakeholders, thereby inhibiting appropriate use of the geospatial data in real-life applications.

Data providing agencies partnering with NSDI at the national and state levels have thus developed and operationalized relational databases for effective search, discovery and sharing of processable data over the Web. Development and maintenance of the India geoportal have been the single window gateway to provide standardized Web-accessible services of the data providing agencies like Survey of India (SOI), National Remote Sensing Centre (NRSC), Geological Survey of India (GSI), Forest Survey of India (FSI), Central Water Commission (CWC), Central Ground Water Board (CGWB), and Ministry of Statistics and Programme Implementation (MoSPI) and several state governments.

Besides the geospatial metadata accessible from the India geoportal in BIS 16439/ISO 19115 standards, a National Data Registry (NDR) prototype containing additional metadata has been demonstrated with registry and catalogue services to facilitate automated search and discovery of map, feature and coverage data services. The NDR contains metadata relating to the feature data definitions, application schemas and classification codes for uniquely identifying geospatial data from various data nodes and correct interpretation of results of geospatial analyses carried out using services from the data nodes of multiple organizations.

A standard operating procedure (SOP) has been prepared for Survey of India′s 1:50,000 scale topographic data reengineering towards development of processable GIS data and provision of Web Feature Service (WFS) in OGC Geography Markup Language (GML) format. Preprocessing and cleaning of the feature data sets have been carried out for the publication of the Web Map Services (WMS) with a countrywide coverage from the data node. Development of SOI′s foundation data layers for Haryana State and publication of feature data sets for WFS/GML access from NSDI portal has been completed and demonstrated. SOI has been in the process of providing WFS/GML for all its 1:50,000 OSM data. Collaborative harmonization of administrative boundaries for the development of the National Foundation Spatial Data (NFSD) up to the revenue village level has been initiated with the involvement of the concerned State SDI set-up in one of the states as a demonstration for adoption of the procedure in other states.

Establishment of a formal linkage with Bureau of Indian Standards (BIS) has led to the development and publication of national standards. ISO standards critical to the development of SDIs at the national and state levels like conceptual schema language (ISO 19103), rules for application schema (ISO 19109), Web Map Service (WMS—ISO 19128), Web Feature Service (WFS—ISO 19142), Geography Markup Language (GML—ISO 19136) are being co-branded as national standards by the BIS. Data content standards on surface geological mapping, forests and soils have been prepared for publication of national standards through stakeholder consultation.

In addition to the national agencies above, state government agencies in Karnataka, West Bengal, Uttarakhand, Odisha, Jharkhand and Haryana holding spatial data sets have collaborated with NSDI as partners for improving their data management procedures. Under the collaborative State Spatial Data Infrastructure (SSDI) initiative with the concerned state governments, state geoportals have been operationalized for provision of Web-based data services. To ensure regular flow of data sets in the state governments from the lower area (villages, block and district) levels to the state level for updating the state geoportals, a coordination mechanism with a GIS set-up has been established at each district.

More effective management and use of the data/images requires their registration, storage and sharing so that those could be put to appropriate processes of governance in line with the provisions of NSDI Resolution, 2006. Registering spatial data sets involves capturing definition/description of each data item, making each item persistently and uniquely identifiable by assigning them unique identifiers, organizing/maintaining the associated classification systems or the code lists for reference by all and a suitable governance system along with procedures for managing the related registers. Moreover, provision of geospatial resources like data, metadata and catalogue is governed by various standards that evolve or change over time. For consistent processing and interpretation of the data and services, it is essential that these changes are kept track of and properly managed. Establishment of registers in the form of a registry with a suitable management structure is thus essential. ISO 19135 prescribes standard specifications on procedures for registration of geographical information items and establishing a management structure.

In line with the end-user requirement stated above and the developments in geospatial technology-related data and process standards, a proof of concept (PoC) of an NDR for NSDI was implemented and demonstrated using data services from Survey of India, National Remote Sensing Centre and the Ministry of Railways IRCTC train running data over a week from the Northern Railway. The PoC success- fully demonstrated the utility of a sample registry, technical architecture and led to the development of an RFP for a real-life NDR implementation for engaging a system integrator. Potential system integrators have provided possible sample solutions around different open source and COTS-based products for the selection of a suitable partner for NSDI for the NDR development.

NSDI uses service-oriented architecture (SoA) in the management of the data and related services both at the national and state levels. A typical SoA (publish-find-bind model) widely used in the provision of geospatial information services is given in Fig. 1.

National- and state-level data nodes use both COTS (e.g. Oracle Spatial) and open source products (e.g. PostGreSQL/PostGIS) for the management of the data sets on the geoportal. Data services are published in the NDR using the registry service accessible at the India geoportal that is accessed by the end-users and application utilities for finding

and discovering the data sets. Once identified, the end-user or application utility binds itself with the data provider for getting the data sets or for meeting any requirement of update of the provider′s database, if necessary, as per the service-level agreements.

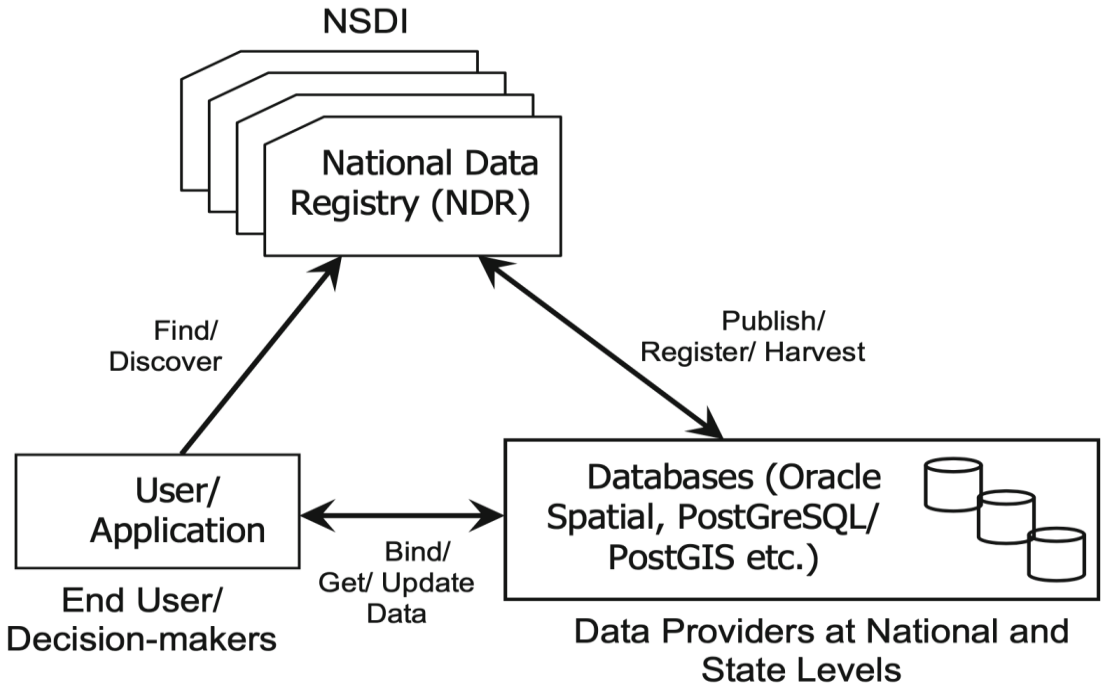


Fig. 1 Service-oriented architecture of NSDI-India—Publish-Find-Bind Model with National Data Registry

Geospatial Cloud : Efforts are currently being made by these nodal agencies to make interoperable Web Feature Services (WFS) accessible for download of feature data in standard encoding specifications (e.g. OGC′s Geography Markup Language) for processing on a GIS platform. More national- and state-level geoportals are likely to be deployed in the near future for provision of feature and attribute data services over the Web. With Web-based data services gradually getting accessible from various agencies, emphasis in NSDI is shifting from enabling ′data services to ′product or ′application services to support provision of GIS products or applications over the Web. In the context of the above service-oriented framework and the GIS application requirement of the end-users and decision-makers, three of the cloud service modes of usage, i.e. Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS), are proposed to be used in the development and implementation of geospatial products and applications. Some of the service models of geospatial cloud as a part of the SaaS proposed to be used include GIS as a Service (GaaS), Application as a Service (AaaS) and ready-to-use Data sets/Imagery as Service (DaaS or Iaas). An experimental geospatial cloud has been developed and demonstrated around the State SDI data sets from West Bengal to the representatives of NSDI and State SDI partnering agencies.

A proof of concept around the above cloud service models is thus under development to explore and demonstrate the utility of the cloud services using sample geospatial data sets prepared for the city of Varanasi (Uttar Pradesh) by Survey of India under the National Urban Information (NUIS) project of Ministry of Urban Development, Government of

India. In addition to the imageries, photographs and topographic sheets of the area, existing data sets are proposed to be made avail- able/accessible for integration with the GIS-ready digital data is of 1:2000 scale on UTM projection and WGS 84 datum as per SOI NUIS data model. Additional 3D content up to LOD-3 (for selected areas only) with appropriate methods and techniques to meet specified quality and accuracy standards has been proposed to be used in the PoC of the geospatial cloud.

Some of the other proposed characteristics of the PoC include unilateral provisioning of services on the cloud by NSDI/SOI, use of appropriate communication bandwidth; providing for placing resources on a specific geographical zone as per the SOI/NSDI′s requirement; near real-time service provisioning and deprovisioning, etc. The PoC is expected to throw light on the performance and sizing of an appropriate geospatial cloud facility for the automated processing and application/product development by the end-user.

R&D Activities : For effective utilization of the above Web-based data and application services by the stakeholders, efforts are being made to develop application prototypes and demonstrate applications with the involvement of user ministries/departments/state agencies and private enterprises. Assignment of unique IDs to plots/cadastres with inputs from the Department of Land Resources (DoLR), train running information and GIS enablement of the Railways with the Ministry of Railways; developing 3D SDI for urban governance; setting up of a GIS Cell in National Disaster Management Authority (NDMA) for consuming WMS/WFS/GML for disaster mitigation; development of GIS applications in watershed development for Watershed Directorate of the Government of Karnataka have been some of the initiatives taken in this direction. The NSDI 2.0 Mission is proposed to be launched for the development of GIS applications for decision support at different levels of governance.

Some of the important priority areas for the future include establishment of Geospatial Research Hubs and conducting R&D in areas like urban governance; village information systems, health GIS; watershed management; disaster management; coastal hazards and urban flood modelling; land resource management; agriculture; geodesy; sustainable development goals; assessment of regional hydrological systems using space-borne gravity observations; heat flux of urban cities; landslide forewarning systems with specific reference to the north-eastern region; interoperability and 3D SDI; large- scale mapping at the level of gram panchayats or wards. A gram panchayat or a ward is invariably a functional area or an electoral unit at the local level comprising of a few revenue villages or households for developmental administration as a part of government′s effort towards decentralizing governance in the rural or urban areas for real-life geospatial application development.

Research & Development in Geo-Information and Communication Technologies (Geo-ICT) domains like ontologies and reasoning, high-performance computing and cyberGIS; geodesy; geospatial interoperability and analytics; cartographic generalization; 3D SDIs; and volunteered geographic information will be pursued with the involvement of a network of academic and research institutions.

Over the past years, training modules have been developed for large-scale building of technical capacity amongst staff and personnel of central and state government agencies and scientists/faculties from research and academic institutions. Development of additional training modules/kits in emerging areas of various relevant domains including Geo-ICT as mentioned above has been an important priority for NSDI.

Management Structure : At the national level, NSDI is managed through a two-tier coordinating arrangement as per the provisions of the NSDI Resolution, 2006, approved by the Union Cabinet as indicated earlier. The apex body, called the National Spatial Data Committee (NSDC), is chaired by Minister of Science and Technology with the concerned secretaries to Government of India as the members. NSDC provides the overall policy direction to the activities of NSDI and advises, guides, authorizes and approves its overall implementation, reviews performance and authorizes/approves any mid-course corrections—including resource prioritization/reallocation. Surveyor General of India and the Director, National Remote Sensing Centre, act as member secretaries of the NSDC. A few professional experts in the domain of geospatial technologies also serve as members.

At the lower tier, the NSDI Executive Committee (EC) is co-chaired by the Surveyor General of India and the Director, National Remote Sensing Centre, with the heads of different data providing agencies of the central government as its members. EC is entrusted with the task of guiding NSDI in implementing the policies/decisions of the NSDC and NSDI′s day-to-day operations. Working Groups/Technical Committees have been constituted in different thematic domains like ′Geospatial Metadata′, ′Data Content Standards′, ‘Ínteroperability′, ′National Data Registry′, ′Geospatial Cloud′; ′Administrative Boundary Harmonization have been constituted with the participation of representatives from the partnering agencies from the national and state levels and leading experts from the IITs, universities and R&D institutions.

Invariably, two-tier coordination structures have also been in place for the State SDIs with the Steering Committee chaired by the chief secretaries with secretaries/principal secretaries of the concerned departments as members at the upper tier for policy-level guidance for the State SDI set-up. At the lower tier, the Executive Committee (EC) is chaired by the secretary/principal secretary, planning and coordination or science and technology with the directors of various state-level geospatial data handling agencies as its members for implementing the decisions of the Steering Committee.

Above coordinating structures are technically advised at the national level by a Steering Committee and several Technical Committees with members drawn from various leading R&D institutions, IITs, universities and laboratories. A Standing Finance Committee (SFC) under the chairmanship of Secretary, DST, with members from NSDI partnering agencies reviews allocation of funds to different activities.

Conclusions : Three major accomplishments of NSDI, so far, have been (i) the establishment of the NSDI mechanism with the enrolment of the stakeholders from national and state levels (ii) the institutionalization of geospatial data and process standards-making and adoption with the involvement of the Bureau of Indian Standards (BIS); and (iii) setting up the technical infrastructure. The technical infrastructure covers hard- ware, software; connectivity; data; metadata; manpower of NSDI and State SDI data nodes for provision of standards-based data and metadata services and applications [8]. Some of the other accomplishments of NSDI include formulation and adoption of a shared vision and goals by various partnering agencies for achieving the NSDI aspirations; framing and implementing relevant policies for a governance framework for data management; and training and capacity building of scientists, officials, staff and personnel of the partnering agencies.

NSDI is now poised towards soon evolving into a national geospatial information infrastructure with its focus gradually shifting to building working linkages with the stakeholder; strengthening the development and sharing of standardized applications and solutions; framing supportive policies and acts for its more effective utilization. Setting up research hubs for pursuing R&D in the emerging areas of Geospatial Information Science and Technology for its continuous reorientation and upgradation; and nurturing international collaborative partnerships with Open Geospatial Consortium (OGC), International Standardization Organization (ISO), and United Nations Global Geospatial Information Management (UNGGIM)′s committee of experts have been set as priorities for NSDI in the coming years. All these are expected to help NSDI achieve its vision of sustaining the economic growth in the short term that in turn will usher in the era of sustainable future.

National Data Registry (NDR) for the National Spatial Data Infrastructure (NSDI)

Introduction : Over the past years, efforts have been made by NSDI to compile and serve metadata of different partnering agencies and re-engineering the feature data sets for improving their use. The NSDI agencies have large amounts of feature data sets and are presently managed in file-based systems largely through quadrangle sheets without any sound strategies for their search and querying. This is evidenced in the present ways to store and manage metadata sets at the NSDI server as per the indices of the quadrangle sheets. Identification and maintenance of such feature data sets pose a major challenge to use of the data. More effective use of the data requires proper registration of the feature data sets so that the data could be put to appropriate processes of governance in line with the provisions of the NSDI Resolution, 2006. Registering spatial data sets involves capturing their definitions and descriptions, making them persistently and uniquely identifiable by assigning them identifiers and organizing/maintaining the associated code lists.

Data registries are in the process of development in different countries to facilitate governance of data sets. Infrastructure for Spatial Information in Europe (INSPIRE) has set up a registry to manage spatial data across various member states of the European Union. The member states have set up national registries to support implementation of the INSPIRE initiative. Open Geospatial Consortium (OGC) has developed specifications for registry services for enabling data providers to register their data sets and services at a common central place. The electronic business Registry Information Model (eb-RIM) specifications have been adopted in developing the OGC specifications for the registry services. ISO 19135 provides specifications for registering data items in a register and related governance processes.

Background : Taking into account the problems in the management of spatial data sets in different NSDI partnering organizations and the absence of a central register for keeping track of the data sets, it has been decided by NSDI, DST to evaluate the concept of NDR and its utility in possible application development to address specific end- user needs. The job consists of working out the specific roles that NDR seeks to play, its scope and structure; develop a few sample but related domain models and the application schemas for implementation of Web-based applications; evaluate the service orientation aspects of the prototype implementation; study some portals playing the role of registry; and recommend steps for actions at the data source level, at the registry (or NSDI) level, and for an early realization of the NDR.

This article has been divided into sections on role of NDR, its scope and structure, an approach for its realization covering the technical specifications, results of the prototype implementation, and the recommendations.

National Data Registry for NSDI : NSDI has been working with national- and state-level data providers to facilitate sharing of spatial data among the stakeholders. This is to be achieved by (i) compiling and providing metadata sets to facilitate discovery and access of spatial data; (ii) setting up of the spatial data nodes for the provision of interoperable spatial data services (e.g. WMS, WFS); and (iii) establishing a single-window access mechanism to the metadata and spatial data sets through installation of a clearing house and geoportals. Metadata sets in BIS standard format have been compiled from various Survey Agencies and State level Line Departments and made accessible from the geoportals (e.g. India Geo Portal at the National and State Geoportals at State Levels).

Problems with the Present Set-up : In the present set-up, metadata sets can be accessed by making queries/searches on the meta-database stored in NSDI or State SDI Data Nodes that are accessed through applications. The following are some of the limitations:

(i) Inadequate access to and maintenance of resources describing the data in order to allow for its correct processing and interpretation by applications for real-life decision support.

(ii) Non-availability of a mechanism to keep track of and manage changes in various rules and standards those govern the above resources for consistent processing and interpretation.

(iii) Even if feature metadata is to be provided by individual data nodes from the data providers, application schemas and code lists (domain value sets or enumerations with thesauri) should be made accessible from the geoportal for search and use. Presently, application schemas or code lists are not accessible.

(iv) Detailed specifications of coordinate reference systems used in data sets, units of measurement, identifier namespaces.

(v) Metadata sets are retrieved for each data unit of the provider (e.g. topographical or geological quadrangle sheets) instead of feature data-wise.

(vi) Inadequate updation of metadata corresponding to changes/updates in spatial data.

(vii) Spatial data sets are not appropriately organized on databases systems (but on file systems) causing major difficulties in accessing/searching data for decision support.

(viii) Although, there are services accessible from the geoportals, there is no meta- data about the services to facilitate their search and discovery.

(ix) Catalogue service as per OGC standard is not accessible.

(x) Machine access to metadata requires XML implementation, but presently no metadata from the portal is in the machine-accessible form.

While these problems are continuously encountered by end-users, concepts, technologies and standards have further evolved and are gradually getting available to address some of the issues. Concepts like geospatial information infrastructure, service-oriented architecture, registry, technologies like geospatial cloud, geospatial platform, interoperability, geosemantics, and standards like catalogue service on web, procedure for

registration of geographical information items (ISO 19135), geography markup language (ISO 19136) are thus required to be explored in this context, and prototypes demonstrated for possible adoption and improvement of the performance of Geospatial Decision Support Systems (Geo-DSS). The concept of ″registry" in particular requires to be evaluated to overcome some of the above problems by studying a few existing portals acting as registries, available standards and tools, review of related literature, defining a role for the NDR, its scope and structure, and recommending a suitable approach for its development and realization for real-life applications.

The Concept of NDR : With several agencies geographically distributed and providing sharable geospatial data, there is a need for end-users—humans or machines—to search, discover, under- stand and access them over a distributed network for use in applications. Towards this, the data-providing agency must draw up and share a set of metadata consisting of the data type, meaning of the features and their associated attributes; underlying schema or structure; classification codes, used if any, in the attributes; location of the data or its bounding box; the coordinate reference system; time, accuracy or resolution of acquisition/survey; standards used in the data format; usage terms and conditions, etc. All these are required to be made accessible from a common catalogue, called a registry, in order to enable the end-user assess the fitness of the data sets in meeting his purpose or application requirements. On satisfactory assessment, the end-user gets access to the data sets from the provider with the help of Application Program Interfaces (APIs) to facilitate automated usage of the data in his/her software pack- ages/products. Such a common and appropriately managed registry at the national level—called a National Data Registry (NDR)—is vital to successful GIS application development by the end users by utilizing geospatial data from multiple sources of data. In effect, NDR links the data providers with the end-users in a service-oriented architecture by providing access to end-users to a common up-to-date system of catalogue.

Interoperability specifications or standards in the context of the above provider–user link assume significance considering the heterogeneity of data sets made accessible from multiple sources in terms of their meaning or semantics, their thematic content and the underlying data formats/structures. Such standards are avail- able from ISO, OGC, BIS or other standard bodies for use in the development of the NDR that are open, precise, unambiguous; comprehensive; extensible; widely acceptable; and consumable by both humans and machines.

NSDI′s present metadata contains information regarding spatial data from various data-providing agencies as per Bureau of Indian Standards (BIS) IS 16439:2016 Metadata Standards for Geospatial Information. IS 16439 standards are founded on the ISO 19115 specifications and have evolved out of NSDI Metadata Standards 2.0. These specifications provide for citation, quality, features, lineage, temporality, reference systems, extent, etc., and are expected to be served to users or their applications as catalogue services that offer the functionalities to store and serve metadata about the data sets. However, the current catalogue specifications do not define formal procedures for the modification of the stored information.

The user does not have the ways and means to ascertain, for example, by whom and when some data sets or services have been modified, added or removed from the database or catalogue. Since data, metadata and standards undergo changes due to data life cycle management in data-providing agencies and development/adoption of new standards or

evolution of existing ones, there is a need to keep track of the changes. Keeping track of the changes facilitates end-user′s sustained access to data and metadata and support correct interpretation of their analyses. NDR provides the framework for tracking such changes. Defining the roles for the NDR and its stakeholders or associated actors in this context assumes importance.

Moreover, provision of these resources like data, metadata and catalogue is governed by various standards that evolve or change over time. For consistent processing and interpretation of the data and services, it is essential that these changes are kept track of and properly managed with the support of an appropriate management structure. Establishment of registers and registries with a management structure is thus essential. These are required over and above the establishment and maintenance of data and service catalogues providing standardized catalogue services capable of getting consumed by end-users or applications.

ISO 19135 prescribes standard specifications on procedures for registration of geographical information items and establishing a management structure. As per the standard document, a ″register" is defined as a set of files containing identifiers assigned to items with descriptions of the associated items. An identifier is a linguistically independent sequence of characters capable of uniquely and permanently identifying that with which it is associated. A ″registry" is defined as an information system on which a register is maintained.

It is therefore essential to maintain registers of different geographical data items and keep track of the data item status for the benefit of the end-user. The registers should be managed through proper governance procedures. ISO 19135 prescribes a common structure for the registers like identifier, name, definition, item class and status. Some of the attributes like description, date of acceptance are treated as optional items.

Roles of the NDR and Its Stakeholders : The data item identifier is a positive integer that uniquely identifies the item in the containing register. The item class identifies a class of geographic information items specified in a technical standard. In the implementation described hereafter it also defines any additional attribute required for describing the items of that class. The item status clearly identifies whether the item is valid at the time it is queried: ″valid" means that it can be used in the production of new data sets.

The content of a register can change over time since there might be the need to introduce new items, retire existing items, replace (supersede) existing items with other items, clarify an existing item to correct the phrasing without changing its semantics, etc. Item status of an item is an indication at any moment in its life the status of the item like not valid, valid, superseded or retired. An item starts in the ″Not Valid" status at the time of a data-providing organisation creating a proposal for a new item. The standards defined in the ISO 19135 could be used to assign various roles to the NSDI that proposes to remain the nodal organization for managing the NDR, while the data-providing organizations could be defining and maintaining their metadata details, application schema, services, coordinate reference systems, code lists, etc., in their respective databases for access. At the minimum, they are expected to provide the WFS, WMS and the CSW. NDR should also consider allowing the private agencies to put up their data and metadata services in the registers. ISO 19135 specifies the following roles involved in the management and use of a registry and the registers it contains. The definitions are mainly taken from ISO 19135.

Registry Manager: The registry manager is the entity that maintains the registry service operational.

Register Owner: The register owner is an organization that establishes a register and is responsible for the content of the register in terms of intellectual property and management. The register owner can delegate the management of the register to a register manager.

Register Manager: The register manager is responsible for maintaining the register. The register owner, if unable to play this role, can appoint a different organization.

Submitting Organization: An organization authorized by the register owner to propose changes to the content of a register.

Control Body: The control body of a register is a group of technical experts who make decisions regarding the content of the register.

Register User: A register user accesses a registry in order to use one or more of the registers held in that register.

Scope and Structure : NSDI uses service-oriented architecture (SoA) in the management of the data assets and related services. A typical SoA (publish–find–bind model) widely used in the provision of geospatial information services is given in Fig. 2. Based on the above service-oriented model, a detailed architecture is proposed for the implementation of registry and other associated components:

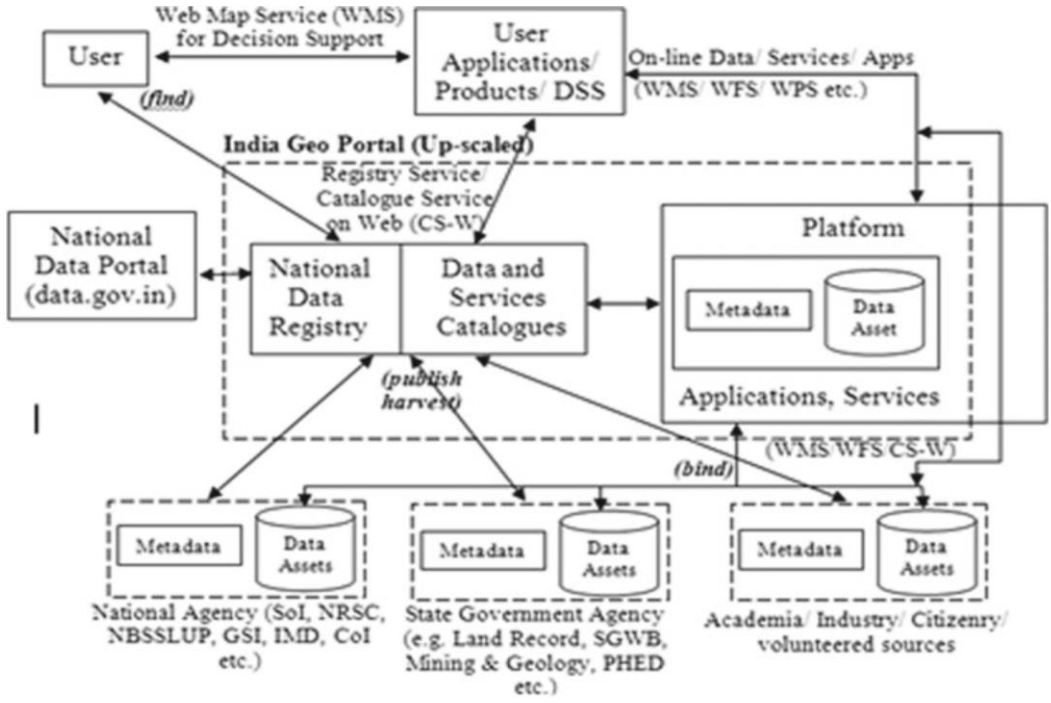


Fig.2 Overview of NSDI technical architecture shown with National Data Registry and data/service catalogues

It is important to note that this architecture primarily separates any content in one of two categories—spatial objects representing phenomena in the real-world (the ″data") and the other items of spatial information, i.e. data description, referenced by or related to the spatial objects, i.e. ″metadata", but in a wider sense than geographic information metadata as understood in ISO 19115.

Data Assets: Data Assets form the core component of the NSDI. These are GIS-processable data sets and could be accessed by Web Feature Services (WFS) by applications and services in the NSDI platform. The Data Assets belong to different national, state agencies or stakeholder groups in the academia, industry or non-governmental sec- tors. The Data Assets are maintained by the concerned agencies and made accessible as services.

Metadata: Agencies publishing their Data Assets information in the data catalogue of the India Geo Portal must make their metadata accessible from their website or portal or the local registers. Setting up the local registers may be considered as an additional job to be completed by the agencies participating in the NDR initiative. Over the past years, various agencies have been establishing their NSDI node with a view to compiling and making accessible their metadata by compiling and uploading those to the India Geo Portal. Considering this additional component to the metadata, it is essential that metadata in respect of each of the Data Assets are maintained by the agencies themselves at their local registers of the data nodes for harvesting and automated updation at the NDR node.

Services: Web Map Services (WMS) provide access to ready-made Data Assets and products for use in applications. Web Feature Service (WFS) helps access to Data Assets for download in different formats including geography markup language (GML). The agencies may consider providing data or service catalogues to the end-users and applications to facilitate discovery and access.

India Geo Portal: Presently, India Geo Portal provides product metadata available for each quadrangle sheet for visualization. In addition, it provides WMS for a select group of survey agencies like SoI, NRSC and FSI or state government (e.g. Government of Karnataka) who have made their data sets accessible from their data nodes. WMS could be viewed concurrently from multiple sources at the India Geo Portal. The India Geo Portal is proposed to be upgraded with additional features like National Data Registry comprising of data/service catalogue and the Geospatial platform for provision of application services (i.e. processed products) for decision support.

National Data Registry is expected to consist of a set of register with items like data specifications indicating the semantics and the characteristics of the types of spatial objects in a data set. The spatial object types provide a classification of the spatial objects and determine among other information the properties that any spatial object may have (be they thematic, spatial, temporal, a coverage function, etc.) as well as known constraints (e.g. the coordinate reference systems that may be used in spatial data sets). This information is, in principle, captured in an application schema using a conceptual schema language standard, which is a part of the data specification. As a result, a data specification provides the necessary information to enable and facilitate the interpretation of spatial data by an application. However, presently, existing spatial data sets are not adequately documented. Thus, in the current proposal, it is proposed that the survey agencies participating in the NDR prototype experiment make concerted effort to document their data assets for building the registers.

With the present emphasis on the transition of NSDI from the development (enabling) phase to the implementation (performing) phase, the ability to consistently reference these resources in the registry through unique identifiers is a vital requirement. There is thus a need to collaborate in a long term on defining common specifications for metadata, data, network services as well as data and service sharing, monitoring and reporting. These are useful in consistently establishing interoperability at the organizational, semantic and technical levels in the NSDI infrastructure. Technical guidelines, data models and code lists are required to be hosted in document and UML repositories, and should be accessible through and maintained. In the long term, a separate dedicated agency may be assigned the task of maintaining these resources on behalf of NSDI.

Approach: There are several key characteristics associated with a register. Every item in the register is associated with a unique, unambiguous and permanent identifier. A register keeps track of changes so that data created in the past can still be interpreted completely and correctly. Superseded or retired register items are also maintained in the registry for future reference.

Worldwide, experiences suggest that the number of registers that eventually are required in an infrastructure is significant. A clear and sustainable operational model forms a key part of the set-up of the infrastructure. However, initially the following kinds of spatial information items could form registers that could be implemented:

- Feature concept dictionary,
- Feature catalogue,
- Application schema,
- Code list,
- Coordinate reference systems and operations,
- Units of measurements,
- Spatial object identifier namespaces,
- Glossary, etc.

The feature concept dictionary establishes a set of feature-related concepts that may be used to describe geographic information. A common feature concept dictionary is proposed to be maintained for all NSDI application schemas and feature catalogues. Conflicts in definitions and meanings of geographical features (e.g. water bodies versus lakes versus ponds) could be overcome by this register. Naming of features at the national and state levels differs significantly and needs to be addressed by setting up a common dictionary accessible to all.

A feature catalogue assumes significance at the time of data acquisition, process- ing and use. A catalogue containing definitions and descriptions of the spatial object types, their attributes and associated components occurring in one or more data sets, together with any operations that may be applied is essential for access by end-users for correct data processing and interpretation.

As per the ISO documentation, an application schema is a conceptual schema for data required by one or more applications. It is a part of data specification and specified in UML. Each data-providing agency at the national and state levels should publish their application schemas in UML/XSD formats for access by human and software users.

A code list is a dictionary describing the attribute value domains for selected property types in a feature catalogue/application schema. The value domain is not fixed in the feature catalogue/application schema, but is managed separately.

Coordinate reference systems and operations are managed in a dictionary of coordinate reference systems, datums, coordinate systems and coordinate operations which are used in data sets.

A dictionary of units of measurement, which are used in data sets, should be maintained as a register. For example, coordinates are presented as geographical latitude/longitude values or in metres.

Spatial object identifier namespaces bear significance considering the fact that similar spatial objects are maintained by different agencies or content providers for varying purposes. A mechanism is required to guarantee uniqueness of object identifiers across various content providers. Identifier namespaces are thus required to be managed.

A register of general terms and definitions used in NSDI data specifications should be prepared and maintained for access by all.

Prototype Implementation: A prototype of the complete system depicted in the above architecture has been implemented for a comprehensive demo of the utility of the registry. The sub- systems of the architecture proposed to be implemented (Fig. 2) include

(i) Database consisting of data assets and the metadata at individual nodes of data providers;

(ii) The registry;

(iii) The platform for developing GI applications/products and services;

(iv) The Geo Portal as a single-window access to data/services/applications;

(v) Decision Support Systems based on end-user workflows capable of consuming various data sets/services/applications to support decision-making by end- users.

(i) Database

The database of a data provider consists of feature data (Data Assets) along with its metadata. The data and metadata from the data provider′s node should be accessible or shareable as WMS, WFS/GML, CS-W. Both feature metadata and service metadata should be stored as per ISO 19115 and ISO 19119 specifications. Data updation is an important component and may be implemented either through database protocols in a local area network from a GIS or using WFS-T from a remote surveyor in the field. Each node should implement a relational database of sample feature data sets on open source or commercial tools for demonstration of services like WMS, WFS/GML, WCS and CS-W.

(ii) The Registry

The registry should contain the description of the data in the form of feature concept dictionary, object catalogue, application schema and a set of procedures for registration of various items maintained in the registry. ISO 19135 standard specifications should be followed in the implementation of the registry.

(iii) The Geospatial Platform

The Geospatial Platform prototype should be developed and implemented to test the utility of the services from various data nodes, processing of the data sets and provision of application/products services to the end-users for decision support. The platform should be accessible as a portal for use by end-users for processing of the data sets for delivery

of products/applications or access to readymade applications from the web or mobile devices.

(iv) The India Geo Portal

The India Geo Portal should be upscaled to provide a single-window access to the data and product services from multiple data providers along with the Catalogue Service on Web (CS-W). A comprehensive catalogue of all the data sets, services, applications and products should be made accessible from the India Geo Portal.

(v) Decision Support Systems

Decision Support Systems based on end-user workflows capable of consuming var- ious data sets/services/applications from either India Geo Portal or Geospatial Platform Portal should be established to support decision-making by end-users.

Implementation Result: In the context of the above framework, different components of the sub-systems have been developed. Experiences of a prototype implementation of the catalogue service along with features like metadata insertion/deletion/modification/harvest available at selected NSDI nodes have been made use of in the implementation of a use case relating to the Railways.

The use case involves locating a moving train between various stations of the Northern Railway on a topographic sheet of Survey of India or/and with Bhuvan imagery of National Remote Sensing Centre (NRSC) of Indian Space Research Organisation (ISRO) along with departure and arrival information at each station. Relevant data sets on departure and arrival of trains have been taken from the Northern Railway and the Indian Railway Catering and Tourism Corporation (IRCTC) of the Indian Railway. Existing data services from NSDI, Surveykshan and Bhuvan Portals have been made use of by a user on the platform of Karnataka Geo Portal. The GeoNetwork tool has been used in the implementation of the sample data registry along with metadata management and catalogue service for demonstration. IIT Bombay implemented the proof-of-concept registers on the GeoNetwork for demonstration. Application schema for SoI is available in UML/GML implementation and developed using Enterprise Architect tool for developing the schema register. Feature concept dictionaries (samples) on topography, surface geological mapping, soils, forests have been developed along with the feature catalogues and code lists for demonstration of registers. A sample screenshot of the prototype implementation of the application has been shown in Fig. 3. As per the use case of train running information and route enquiry, the application shows the actual location of the selected train on the combined WMS display of topographic sheet of Survey of India and the satellite imagery of the National Remote Sensing Centre.

Implementation of the NDR prototype containing sample registers from SOI, GSI, FSI, the Indian Railways and demonstration of its utility in automated processing of spatial data for a selected use case have thus been successful. NDR has the potential to help overcome the issues relating to sound governance and utilisation of the spatial data sets by NSDI in India.

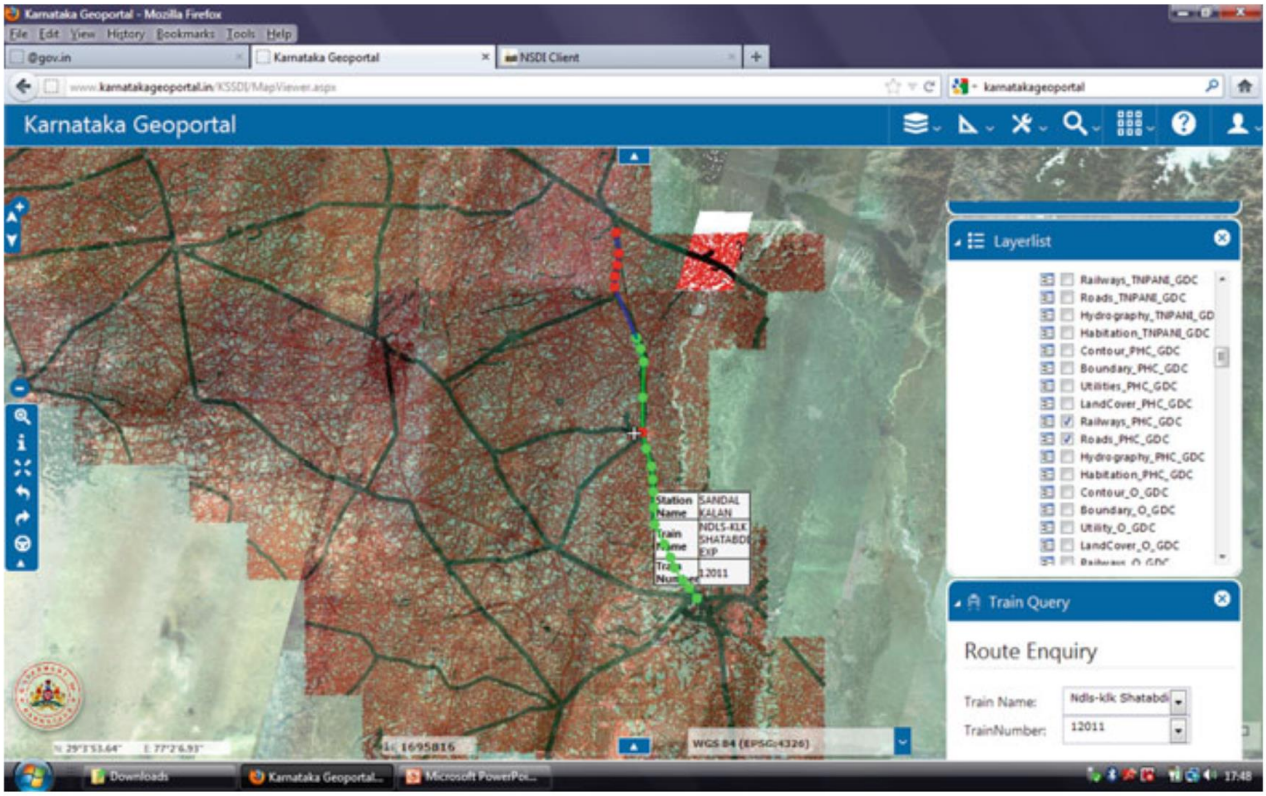


Fig. 3 Sample screenshot showing the train route and location on the SOI topographic sheet and NRSC′s Bhuvan imagery coming from different sources

Recommendations: NDR is a useful concept and has the potential to overcome the problems of search and access and automated processing of spatial data sets from the NSDI agencies. NDR platform should be operationalised by initially linking it up with a few (say 2–3) agencies to share their metadata and services and then gradually covering more agency nodes in an incremental manner in order that the implementation could be iteratively improved through the process of verification and validation. Considering that the ingredients of NDR and their utilities have been understood through demonstration of a proof-of-concept in the Indian context, professional agencies should be involved to operationally develop and implement the NDR. Harvesting should be a part of the NDR utility for automatic and periodic updation of metadata. In particular, focus of the implementation should be on development of domain-specific application schemas using ISO/OGC/BIS standards, existing data sets re-engineered and new data sets appropriately engineered using the standards-based feature model for ensuring interoperability; setting up spatial databases and application systems to provide WFS and WMS services; identifying use cases for provision of web processing services based on WPS and RESTful Service standards; setting up necessary system platform, hardware and software for operationalising registers and required processing services; demonstrating search on the NSDI partnering agency sources; and preparing a few case studies for demonstrating discovery and use of data and services from the NDR data nodes for training on integrating the web-based services with the end user′s business workflows.

Development of State Spatial Data Infrastructure (SSDI): Indian Experience

Introduction : In its journey of planned development, the current emphasis in India is on local-level planning. The concept of spatial planning has been brought in to strengthen it. The constitutional support has come in the form of 73rd and 74th amendments, while Geo- graphical Information and Communication Technology (Geo-ICT) has been adopted as the main tool for achieving it. The Government of India initiated a number of Geo-ICT-based programmes to support the local-level planning in 1980s, viz. Natural Resources Data Management System (NRDMS) of the Department of Science and Technology, National Natural Resources Management System (NNRMS) of the Department of Space (DOS) and Geographical Information System (GISNIC) and District Information System (DISNIC) of the National Informatics Centre (Ministry of Communication and Information Technology). These programmes had demonstrated the utility of spatial data in generating information required for efficient decision-making, as a result since early 90s there has been considerable awareness among local administrators about Geo-ICTs. In order to facilitate and coordinate the availability and access of spatial data between stakeholders at all levels of government, National Spatial Data Infrastructure was established in 2006.

However, non-availability of and inaccessibility to spatial data of the desired resolution and currency, incompatible data sets and inadequate capacity among the officials of the local government departments (LGDs) remained the major bottle- necks to the utilization of National Spatial Data Infrastructure (NSDI) for local-level planning. In order to obviate the same and create synergy between spatial infrastructure at national level and state level, decision was taken during the Chief Secretaries Conference held on 4–5 February 2011 for the establishment of State Spatial Data Infrastructure (SSDI) by the Department of Science and Technology, Government of India. In October 2011, National Spatial Data Committee (NSDC), chaired by the Honourable Minister of Science & Technology—apex body for the formulation of Spatial Data Policy had approved the creation of SSDI.

Globally, the experience of development and operationalization of SSDI is very limited, especially in the developing world. In the developed world, there are some experiences in Australia, USA, Europe and Canada. In Australia, state governments play a significant role in policy development and the building and managing of spatial data infrastructures. Each of the Australian states and territories has established a coordination agency or group to reflect each of their mandates and state goals with respect to spatial data infrastructures. The state government agencies are active in pursuing SDI development with most activity generally focussed on delivering product outcomes. Each state has an overarching policy to facilitate SDI development which usually includes encouraging the active participation of the private sector in their SDI vision. In the USA, individual state coordination bodies have generally shouldered the majority of the SDI coordination responsibilities, e.g. Maryland, Illinois, California. In addition, the Federal Geographic Data Committee (FGDC) has encouraged the development of SDIs at sub-national levels through partnerships and collaboration. Müller and Würriehausen has reported a case study of local SDI implementation in the South Western German State of Rheinland-Pfalz it in the context of the evolution at higher SDI levels represented by the INSPIRE initiative at the European level and by the GDI-DE initiative at the German national level.

The Canadian Geospatial Data Infrastructure (CGDI) is developed by the Natural Resources Canada to provide open, secure and continually available access to comprehensive location-based information about Canada through the community-

sustained CGDI in support of prosperity and well-being for all Canadians. In British Columbia, the provincial Spatial Data Infrastructure (SDI) is utilized by legislated and mandated lines of business such as resource development, water management, land tenure, transportation, public safety and emergency response.

The main objectives of SSDI in India are:

- To develop and operationalize a standard framework in states for the purpose of sharing and exchange of spatial data sets from various state-level line departments/agencies
- To utilize the spatial data sets from the above framework in GIS operations required for decision support by various stakeholder communities
- To create awareness and build the capacity of various stakeholders for carrying out various activities of SDIs.

Development of SSDI: In order to realize the potential of spatial data to be made available for planning processes at various levels, the Department of Science and Technology (DST) through its NSDI (National Spatial Data Infrastructure) initiatives has supported the establishment of State|Spatial Data Infrastructure in some states on competitive selection basis. However, this would require a synergizing effort between various entities/stakeholders involved towards creating a network of state data nodes for operationalization of State SDIs.

Key Components of SSDI

The key components required for successful operation of a SSDI are:

- People: Implementing agency, data and ICT infrastructure providers, policy-makers and users.
- Processes: Data acquisition, data management, data availability and sharing.
- Technology: Hardware, software, geoportal services, and applications.
- Policy.

Resource Requirement

IT Infrastructure and Processes: The system architecture shown in Fig. 4 represents the hardware and software required in the development of a geoportal for SSDI. The geoportal has to be designed using Web-enabled GIS Software Supporting RDBMS (open source/proprietary) for delivering dynamic maps and related data and services via the Web. It should operate in a distributed environment that consists of both client-side and server-side components. Typically, the client will request information from an Internet server holding the data repository. Then, the server will process the request and send the information back to the client viewer. The server components, i.e., the Web server/application server and the data server, will form a part of the server architecture. Only authorized clients will have access to the server application and database. For a better performance, this architecture should also include two backup servers.

Open source/commercial off-the-shelf SDI software package interoperable to various OS platforms will be required to provide various Web services, viz. Catalogue Service on Web (CSW), Web Map Service (WMS), Web Feature Service (WFS/GML), Web Registry Service (WRS) and Web Coverage Service (WCS).

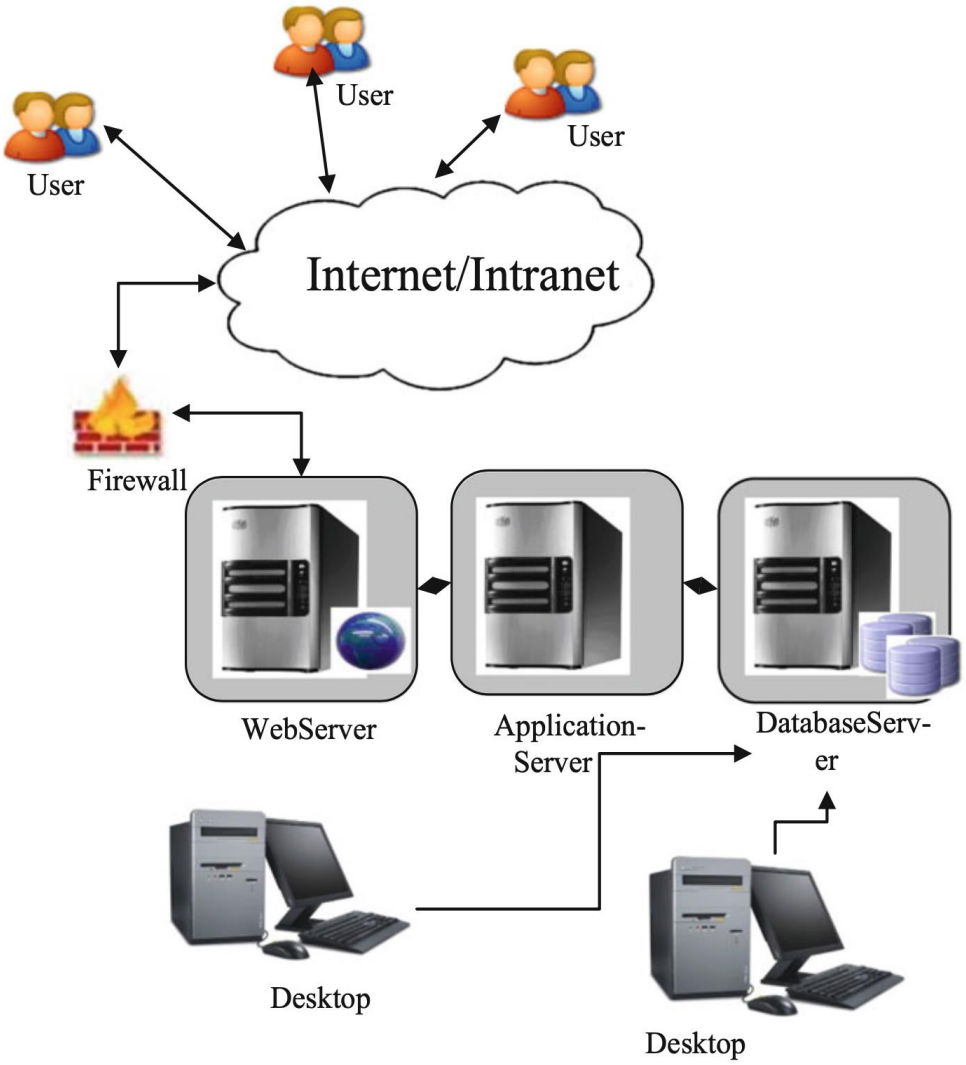


Fig. 4 Systematic representation of a common state′s spatial database infrastructure (system architecture)

Skill Required:

The indicative technical skill sets required for the development of a SSDI are GIS expertise; thematic expertise; IT expertise (website developers and managers, data/system administration software developers and programmers, security related, etc.); information risk management expertise; other expertise on need basis, etc.

Methodology

The following generic steps would be required to ensure the successful implementation of SSDIs (Fig. 5):

• ***Selection of nodal agency:*** The nodal agency for the implementation of SSDI is selected based upon their technical/organizational capacity in geospatial information management (GIM).

• ***Selection of system integrator:*** RFP document should be prepared by the nodal agency for the selection of the vendor for setting up the state geoportal/data clearing house as well as developing state, district and block data nodes.

• ***Identification of stakeholders and need assessment:*** Identifying the users/user groups already associated or to be potentially associated with the use of geospatial data in the context of developmental planning is an essential step. This could be done through a state-level workshop/meeting, etc. Interviews should be conducted with various line departments/agencies of the state government to assess their information needs.

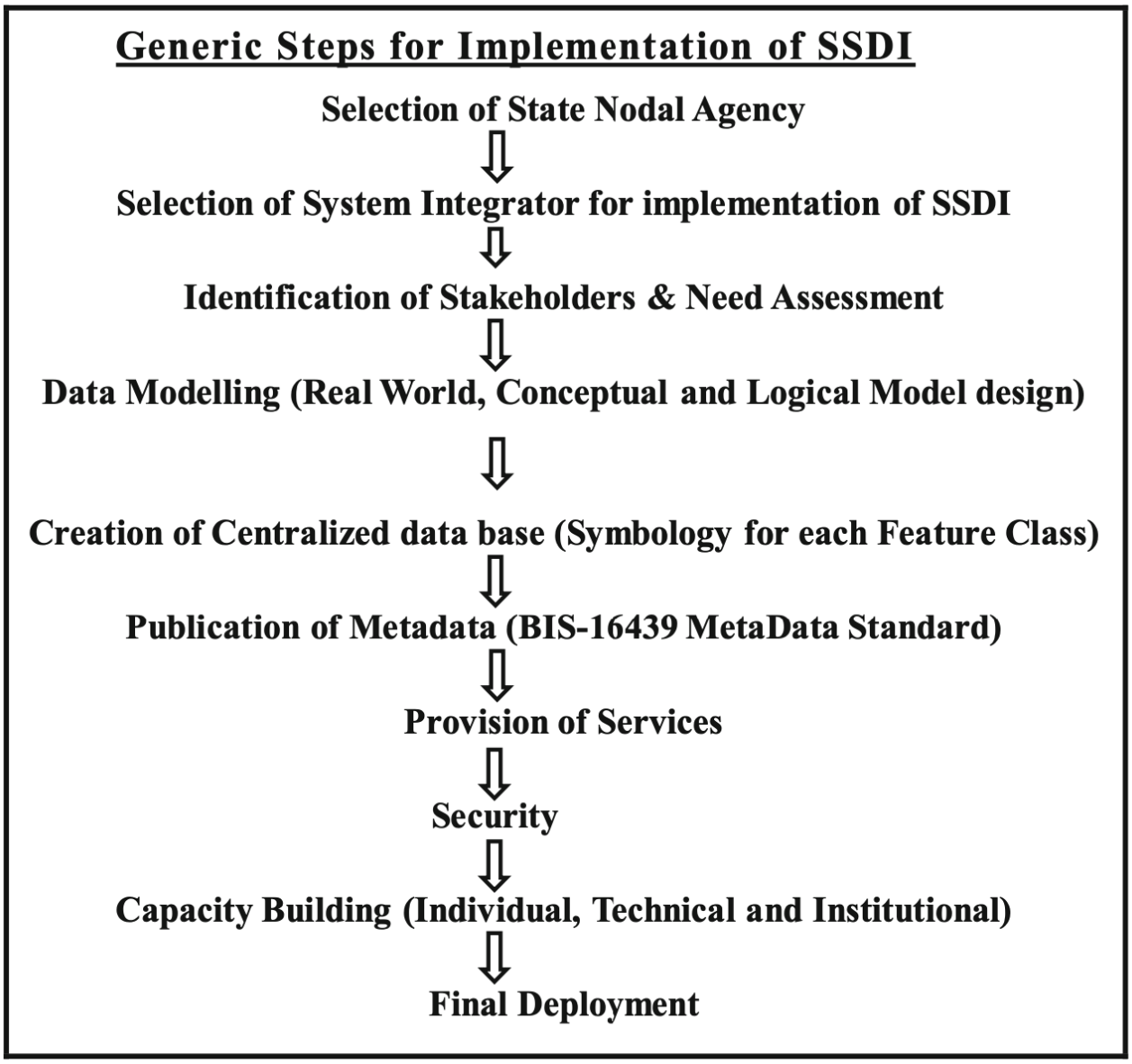


Fig. 5 Common steps for development of state geoportal/data clearing house

• ***Data Modelling***

– *Creation of real-world object catalogue:* Based on the need assessment, a detailed catalogue of underlying real-world objects clearly defining each object should be drawn up. A real-world object catalogue is useful in developing the data models (conceptual/physical) for the implementation.

Conceptual Data Model: A conceptual data model bringing out the objects and the associations is required to be developed and appropriately documented. The conceptual model should address software recommendations, refinement of physical system configuration (servers, network, storage requirements, etc.).

- ***Creation of a centralized database:*** Initially, a Web-enabled centralized database of various existing spatial, attribute or statistical data should be developed at the state node to store spatial, attribute or statistical data sets already available with the nodal agency and line departments. Proper indexing mechanism of data sets should be adopted to facilitate efficient query/access. Mechanism for updating the existing data sets on the database using OGC standards-based Web Feature Service (WFS) should be provided to facilitate upgradation/maintenance of the database from remote clients located in the individual line departments/agencies of the state government, GIS data centres/cells, viz. district NRDMS centres.

- ***Publication of metadata***: In order to support easy discovery and access, various geospatial data providers in the state should publish their metadata sets into the geoportal/centralized database following metadata standards prescribed in BIS 16439.

- ***Provision of services:*** After following the specifications of OGC′s geospatial portal reference architecture, a geoportal (a website for SSDI) should be developed, demonstrated and installed to provide portal services/portrayal services/data services, and catalogue services.

- ***Security system to handle data, user identity and network:*** In order to secure the geoportal/clearing house from unauthorized access, an appropriate security software module having provisions to safeguard data sets, manage user identity and transaction security, detect unauthorized intrusion, permit authorization/authentication, and non-repudiation-based access controls on resources is required.

- ***Capacity building of stakeholders:*** In order to build up individual, technical and organizational capacity, training workshops at the state and organizational levels should be organized.

- ***Final deployment:*** Based on the user feedback, the complete system should be integrated and operationalized for use. The complete system and its use should be presented in a series of workshops in different parts of the state having participants from groups like elected representatives, officials from different tiers of the governmental hierarchy from the state, district, tehsil, and village, other employees of different concerned organizations, and selected citizens.

State/district data layers	State/district data layers
Agroclimatic zones	Drainage
Taluk/district boundary	Basin boundary
District headquarters	Catchment boundary
Division boundary	Subcatchment boundary
Division headquarters	Subdivision boundary
Geology	Subwatershed boundary
Meteorological station	Tanks
Parliamentary constituencies	National highway
Legislative assembly constituencies	State highway
Rail network	Major district road
Reservoir	Other district road
Rail gauge station	Village road
River	Airport

Table 2 List of data layers required to make foundation of a SSDI

Data Layers

The data layers displayed in Table 2 should make the foundation of the SSDI. Additional thematic layers could be added depending on the availability of data on additional themes and future user needs.

Management Structure for Governance of SSDIs

The management arrangements may comprise of a three-tier organization structure consisting of the following committees:

- ***State Spatial Data Committee (apex body):*** A State Spatial Data Committee (apex body) should be constituted under the chairmanship of a senior official of the level of Chief/additional Chief Secretary or Secretary Planning with membership drawn from Secretaries of line departments concerned with spatial data in the state.

- ***SSDI Executive Committee:*** Committees similar to the Executive Committee may be constituted at the district level, headed by the district collectors with heads of various line departments in the districts to coordinate spatial data management.

- ***GIS cell:*** In order to coordinate among different line departments and office of the district collector/magistrate, a district GIS cell should be established at headquar- ters of each district. The cell should update its GIS data on daily, monthly and annual basis.

Nodal officers should be identified in the line departments at state and district levels for coordinating with the GIS cell.

Enabling Policies: Geospatial policies governing spatial data sets and processes constitute an important component of Spatial Data Infrastructures (SDIs). Various policies in vogue regarding different aspects of data/information are as follows:

National Map Policy (2005) defines the scope, distribution and liberalized access of digital Survey of India (SOI) topographic maps to user groups without jeopar- dizing national security.

Civil Aviation Requirement (CAR) was issued in 2012 detailing the procedure for the issuance of flight clearances for agencies undertaking aerial photography, geophysical surveys, cloud seeding, etc.

Remote Sensing Data Policy (RSDP, 2001 & 2012) defines the distribution pro- cess of satellite images to users.

National Data Sharing and Accessibility Policy (2012) ensures proactive and open access to the data generated through public funds available with various departments/organizations of Government of India.

There are also the Information Technology (IT) Act (2000); the Right to Information (RTI) Act (2005); and various State-Level Data Sharing & Accessibility Policies getting framed by various states to improve sharing and accessibility. Despite the availability of the above policy framework, it has not been possible to discover and access geospatial data sets easily. Towards overcoming the above problems, a comprehensive National Geospatial Policy (NGP) is under formulations covering geospatial data, products, services and applications.

Best Practices in the Implementation of SSDI: Various state government agencies in states like Karnataka, West Bengal, Uttarakhand, Odisha, Jharkhand, J&K, Nagaland, Punjab and Haryana holding spatial data sets have collaborated with NSDI as partners for improving their data management procedures by developing GIS data assets (Table 3). Under various State Spatial Data Infrastructure (SSDI) collaborative projects implemented in cost-sharing mode between the DST Government of India and the concerned state governments, the agencies have either operationalized or demonstrated state geoportals/or their prototypes, worked on contract management for engaging system integrators, standardizing spatial data sets for the provision of Web-based data services in the framework of service-oriented architectures (SOA), and set up coordination mechanisms in the state governments. The best practices of various states in technological implementation, development of institutional mechanism and capacity building along with applications in governance are shared below.

S. No.	States	Funding status	Geoportal status	Data sharing policy	Long-term sustenance mechanism	Institutional mechanism
1.	Karnataka	Rs. 253 lakh (Rs. 192 lakh/Rs. 61 lakhs)	Operational	Draft ready	Yes	Coordination structure
2.	West Bengal	Rs. 1178.98 lakhs (Rs. 477.38 lakhs/Rs. 701.60 lakhs)	Prototype	Draft ready	Yes	Coordination structure
3.	Jammu and Kashmir	Rs. 377.72 lakh (Rs. 264.40 lakh/Rs. 113.32 lakh)	Prototype	Yet to initiate	Initiated	Initiated
4.	Uttarakhand	Rs. 375.63 lakhs (Rs. 251.68 lakhs/Rs. 123.9 lakhs)	Operational	Draft ready for finalization	In the process	Well-established coordination structure
5.	Haryana	Rs. 203 lakhs (Rs. 125 lakh/Rs. 78 lakh)	Operational	Yet to initiate	Initiated	Process initiated
6.	Odisha	Rs. 650.02 lakh (Rs. 383.3 lakh/Rs. 266.72 lakh)	Operational	Odisha Spatial Data Policy in 2015	Yes	Coordination structure
7.	Jharkhand	Rs. 195.49 lakh (Rs. 181.35 lakh/Rs. 14.14 lakh	Operational	Draft ready	Yes	Coordination structure
8.	Nagaland	Rs. 184.95 lakh (Rs. 123.76 lakh/Rs. 61.19 lakh)	Data layers identified for upload	Initiated the process	Not yet	Not yet

Table. 3: Representing status of spatial data infrastructure readiness in the various SSDI implementing states in the country.

Operationalization of the Geoportal: Karnataka Experience: The Karnataka State Council of Science and Technology (KSCST) with the support of state and central government have developed a geoportal (Fig. 6) and data clearing house to discover/access spatial data sets useful in the local-level planning. Karnataka Geoportal is a centralized single window access mechanism for all the spatial data acquired by various agencies. The council has institutionalized the geospatial technologies for informed decision-making by establishing district NRDMS centres in all the thirty districts of Karnataka with the support of Government of Karnataka. The available data is catalogued, and the search for the availability of any data set is made available through metadata.

The complete Karnataka Geoportal is developed using an OGC-compliant proprietary software with facilities to share the vector and raster data sets through WMS, WFS and WCS Web services. The geoportal has been kept operational and maintained by the council through funding support by the state.



Fig.6: Screenshot of the Karnataka Geoportal (http://www.karnatakageoportal.in)

Institutional Framework and Capacity Building : Apart from technologies, appropriate institutional framework and capacity building are essential for long-term sustainability of SSDIs. Keeping this in view, many SDI implementing states such as Karnataka, Odisha, Madhya Pradesh Uttarakhand and Jharkhand have already published in the process of publishing State Spatial Data Policy to promote sharing and enable access to the government-owned data. For example, Government of Odisha has published Odisha Spatial Data Policy through its Gazette No. 1270, Dt. 29-08-2015, to facilitate easy access and sharing of government-owned data in open format for supporting sustainable and inclusive governance and effective planning, implementation and monitoring of developmental programmes, managing and mitigating disasters and scientific research aiding informed decisions, for public good.

Among SDI implementing states, Uttarakhand (UK) has shown a best example of capacity building and coordination mechanism. The Uttarakhand State has a coordinating structure in the state government with nodal officers identified at the state/district levels. For capacity building of the state government personnel and staff, various district-wise sensitization and training workshops have been organized where the primary focus has been on exposing them to application of Web-based geospatial technologies; providing hands-on training on GIS development and data capturing through GPS; information need assessment; and drawing up a road map for SDI development as per their own needs. The

state government has also established a GIS cell at the headquarters of each district for coordinating the SSDI activities. The GIS cells at districts are integral to State SDIs to support geospatial data upgradation, publishing and sharing up-to-date data as WMS/WFS/GML, and utilization of GIS in various applications.

Applications in Governance: The utilization of geospatial data and services for a wide range of uses has seen steady growth in the requests for both data and services by planners and administrators. The NRDMS-NSDI programme of DST is continuously updating its data sets in diverse fields with an increasing set of application requirements. One of the successful examples is in watershed management.

Use of Geospatial Technologies for Watershed Management: The KSCST has showcased the utilization of geospatial technologies by developing geospatial applications on Karnataka Geoportal to evaluate watersheds in Belagavi Division of Karnataka. The council has integrated the KWDD′s MIS with the Web-based SDI approach to provide standards-based online geospatial information services to end users in KWDD by utilizing the Karnataka State Geoportal already operational in the state. Earlier, KWDD does not have an easy and timely access to geospatial data of right resolution and currency for use in planning, implementation, monitoring, and evaluation processes. The geospatial services like multi-spatial-attribute queries; mobile compatibility; crowdsourcing; online editing of data and integration of MIS are the highlights of this development. Other portlets such as monitoring of biogas programme, health GIS, location of train services have also been demonstrated to the end users to support planning.

Future Directions : Rajabifard et al. proposed that the future of SDI lies in addressing the balance between the competing foci in SDI development to encourage process-based facilitation for participant initiatives for spatial data sharing. While ongoing content development, a product-based approach, is essential to complement process-based facilitation, with the main aim to link existing and potential databases of the respective political/administrative levels of the community.

In order to maintain this balanced approach of Indian SSDI development, some of the considerations for the technological requirement are as follows:

New Techniques to handle Geospatial Data Streams : With the development of geo-sensor networks in various geo-domains (e.g. smart cities, agriculture, hydrology), human sensing, etc., geospatial streams are going to be one of the new modes of data. There are need to upgrade SDI to handle geostreams, interfaces to process and analyse these streams, development of domain-specific techniques/algorithms for events detection and monitoring and geospatial complex event processing (CEP) approaches.

Developing Approaches for Knowledge Representation of Geospatial Information: Geoinformation is highly diverse and needs approaches for reconciliation and integration at various syntactic, semantic levels. Geoinformation generated by various application projects needs to be converted to knowledge and represented formally. Thus, new ways of querying and reasoning on knowledge to obtain actionable intelligence are required. National-level geo-knowledge platform should be developed to provide various tools for knowledge representation, reasoning and visualization. There is need to develop controlled vocabularies, emergence of interdisciplinary programme on geo-ontology engineering.

Linked Geospatial Data : With the growth of multimedia, social networks, news, Twitter, user comments, etc., there is a need to develop approaches to link geospatial data with other forms of data available online to create various views of geospatial data in conjunction with other data. Thus, approaches need to be developed so that geospatial data conforms to the linked data concepts. For example, enabling RDF data available on the Web, and interconnect it with other data with the aim of increasing its value for user, enabling the development of geospatial linked data graphs, etc.

Spatial Data Fusion : New research directions in data fusion approaches should be explored to develop fusion models of multi-sensor, multi-source, multi-temporal geospatial data, which are also scale- and rotation-invariant. India specific fusion products should be identified, and standardized work flows for geospatial data fusion for various applications including near real-time applications should be published. This should be based on the type of product required for that application.

Big Data Analytics and Geo-Computational Systems : With the emergence of geospatial big data processing approaches, there is a need of development of geo-computational platforms integrated with SDI big data analytics techniques that are domain-specific.

Geospatial Approaches for Critical Infrastructures Protection (CIP) : Critical infrastructures are under constant threat from various man-made and natural disasters and other subversive activities. Understanding how resilient these infrastructures are after an event is critical. Also, there is a need to understand the interdependencies between the critical infrastructures. Thus, research is needed on deterministic and stochastic approaches for interdependency modelling, development of simulation environments, situational awareness, visualization.

3D Visualization : There will be an increase in the ways we visualize geospatial data, moving from a mapping environment view to a view that demonstrates how the user would experience a location as if their feet were on the ground, e.g. street views in Google Earth. Three-dimensional building models will continue to grow and help to create realistic views of our landscape. Geospatial data is critical in helping to supplement 3D views of other geo-coded information to provide 3D business intelligence. Three-dimensional visualization will be fed by new semi-structured data from mobile devices, geo-tagging of existing enterprise structured data, and tapping into new streams of location-aware unstructured data.

Location-based Business Intelligence : Solving business problems with geospatial data and cloud computing will become increasingly important in future. More and more geospatial solutions and 3D business intelligence services that provide customers with ″answers" rather than ″data" need to be developed. Increasing complexity of geospatial solutions, and the continued growth in the geospatial technology industry, will lead to both business consolidation as well as increasing partnerships.

Crowdsourcing : In an increasingly connected world, volunteered information will become more and more important. Information created in this way will be increasingly important for government and business and may radically challenge traditional approaches to geospatial data generation and maintenance.

The Puzzle of The Geospatial Technology Legal Framework

Background: Geospatial technology is a multidisciplinary field that covers various forms of technology that are implemented in fields such as archaeology, geology, geography,

statistics, etc. At present, there are a multitude of laws in India with respect to geospatial technologies and the regulation of geospatial data. This article attempts to enumerate the various legislations currently in force and the draft stage.

The different types of geospatial technologies include the following:

1. Remote Sensing: this includes images and data collected by instruments from space – or through aerial cameras and sensor-based platforms.

2. Geographic Information Systems (GIS): This includes software-based tools for mapping and examining data collected and the georeferencing of data. These systems are put to use to detect geographic patterns, such as disease clusters stemming from toxins, sub-optimal water access, etc.

3. Global Positioning System (GPS): a network of satellites which can give precise coordinate locations to civilian and military users.

Indian Framework : The usage of such geospatial technology results in the creation of geospatial information. In the Indian context, geospatial information has been defined under the draft Geospatial Technology Bill, 2016 (″draft Bill") as ″geospatial imagery or data acquired through space or aerial platforms such as satellite, aircrafts, airships, balloons, unmanned aerial vehicles including value addition; or graphical or digital data depicting natural or man-made physical features, phenomenon or boundaries of the earth or any information related thereto including surveys, charts, maps, terrestrial photos referenced to a co-ordinate system and having attributes."

The definition of geospatial information has been kept very open-ended and can potentially incorporate everything from satellite imagery, to books, navigation systems, newspapers, magazines, town plans, survey data, to every smartphone that bears a GPS chip.

Geographic Information Systems: Traditionally, mapping has been an activity solely reserved for the Survey of India, which was formed in the year 1767. However, the National Map Policy of 2005 was released on May 19, 2005 due to the recognition of the importance of high quality spatial data in various facets such as conservation of natural resources, socio-economic development, infrastructure development etc. The intent of this policy was to ″liberalize access" to spatial data without compromising security concerns. With the aim of realizing the security concerns, a dual-classification was designed with respect to the maps, namely – i) Defence Series Maps (″DSM") and ii) Open Series Maps (″OSM"). While the DSM constitutes of topographical maps that mainly cater to defence and security requirements of the country, the OSM supports developmental activities.

Henceforth DSMs, irrespective of whether they are in analogue or digital form, shall be classified under this category and the power to issue guidelines with respect to their usage lies mainly for developmental purposes. They are not openly accessible ipso facto and need to gain the ′unrestricted tag after clearance from the Ministry of Defence.

While the DSMs are completely classified, restrictive provisions regarding usage and dissemination of OSMs have also been incorporated in the policy. OSMs are not allowed to show any civil and military Vulnerable Areas and Vulnerable Points (VA′s/VP′s). OSMs on a scale larger than 1:1 needs to be disseminated either by sale or an agreement, which will allow the entity engaged in the activity of mapping to add its own value to the maps obtained, and to share these maps with others.

Remote Sensing : In 2011, the confusion pertaining to applicability of the National Map Policy of 2005 to both territorial and satellite mapping was resolved with the release of the Remote Sensing Data Policy of 2011. The policy recognized the importance of remote sensing data and noted that it was largely used by government and non-government users from Indian and foreign remote sensing satellites.

However, again banking upon the need for security considerations, the policy was released with the purpose of "…managing and/ or permitting the acquisition/dissemination of remote sensing data in support of developmental activities". The Department of Science ("DOS") was made the nodal government agency for all actions pertaining to remote sensing data under the policy.

A perusal of the policy indicates a parallelism between the Remote Sensing Policy of 2011 and the National Map Policy of 2005. Thus, similar to National Map Policy of 2005, Remote Sensing Policy of 2011 assures of a government managed Indian Remote Sensing Satellites (IRS) Programme, the data produced by which will be owned solely by government, and any users other than the government would be provided with licences on a case to case basis, only if such need arises. It further provides that any attempt at acquiring and/or dissemination of remote sensing data within India shall require permission through the nodal government agency.

National Remote Sensing Centre ("NRSC") of the Indian Space Research Organisation (ISRO)/ DOS is vested with the authority to acquire and disseminate all satellite remote sensing data in India, both from Indian and foreign satellites. NRSC is also supposed to maintain a systematic National Remote Sensing Data Archive, and a log of all acquisitions/ sales of data for all satellites. Therefore, nodal government agencies were established for both terrestrial mapping and satellite imagery, former being Survey of India and latter NRSC.

Civil Aviation – Operation Of Drones: Drones, as we know them today, represents a significant development in robotic technology. Unmanned aerial vehicles, or Remote Piloted Aircraft Systems ("RPAS"), as termed by the International Civil Aviation Organisation have been defined as "a set of configurable elements consisting of a remotely-piloted aircraft, its associated remote pilot station(s), the required command and control links and any other system elements as may be required, at any point during flight operation."

In December 2018, the Director General of Civil Aviation issued the Civil Aviation Requirements 1.0 ("CAR") under Rule 15A and 133A of The Aircraft Rules, 1937. The CAR classifies RPAS based on their weight (including payload), as under:

1. Nano – under 250 grams.

2. Micro – between 250 grams and 2kg.

3. Small – between 2kg and 25kg.

4. Medium – between 25kg and 150kg.

5. Large – greater than 150kg.

Eligibility for operators of RPAS:

1. Citizen of India; or

2. Central Government or any State Government or any company or corporation owned or controlled by either of the said Governments; or a company or a body corporate provided that:

3. it is registered and has its principal place of business within India;

4. its chairman and at least two-thirds of its directors are citizens of India; and,

5. its substantial ownership and effective control is vested in Indian nationals; or

6. Company or corporation registered elsewhere than in India, provided that such company or corporation has leased the RPAs to any organization mentioned as above.

For all RPAS other than those falling under the nano category, the mandatory equipment required for operation are:

1. Global Navigation Satellite System (GPS);

2. Return-to-home;

3. Anti-collision light;

4. ID plate;

5. Flight controller with flight data logging capability; and

6. Radio Frequency Identification (RFID) and SIM/ No Permission No Takeoff.

Additionally, RPAS would be required to operate within visual line of sight, during the day and only upto a maximum altitude of 400 feet. The CAR also demarcate the permissible zones for operation of drones into three categories:

1. Red Zone: operation of drones not permitted

2. Yellow Zone: this is a controlled zone and operation of drones would be subject to prior approval. For operation of drones in this zone, filing of flight plans and obtaining Air Defence Clearance/ Flight Information Centre number would be necessary.

3. Green Zone: this would form the uncontrolled airspace with an automatic permission for operation of drones.

The Regulations also define No Drone Zones which would cover the following areas:

1. Radius areas of 5 kms from airports;

2. Within a radius of 50 km from the international borders;

3. Within a radius of 5 km from Vijay Chowk; and

4. Buildings such as State Secretarial Complex in State Capitals, strategic and military installations.

The enforcement actions provided for include:

1. Suspension or cancellation of registration or permit;

2. Penalties under the Aircraft Act, 1934 or Aircraft Rules; and

3. Penalties under Indian Penal Code such as:

4. Section 287 – negligent conduct with respect to machinery; or

5. Section 336 – act endangering life or personal safety of others; or

6. Section 337 – causing hurt by endangering life or personal safety of others; and

7. Section 338 – causing grievous hurt by act endangering life or personal safety of others.

The Drone Policy 2.0 was released on January 15, 2019, which sought to address issues of Beyond Visual Line of Sight (″BVLOS") and regulate autonomous operations. The key changes proposed were:

1. Privacy by Design – Manufacturers to adhere to a privacy by design standard, eliminating risks of future privacy harms by operators.

2. Drone Corridors – To segregate air routes of commercial airliners and RPAS, limit human presence, enable autonomous takeoff and landing at designated drone-ports.

3. BVLOS and night-time operations – as opposed to the current visual line of sight of 400ft, and day-time operations only.

4. Droneports – To facilitate takeoff and landing, operate as distribution centers/ cargo holds and battery charging stations. They must be integrated with Digital Sky Platform and listed on the National Droneport Registry.

5. Unmanned Aircraft System Traffic Management (″UTM") – Hyper-local and real-time tracking and management of UAS induced traffic in Drone Corridors and detect obstacles and avoid collisions. UTM will give Digital Sky the ability to electronically disrupt operations of a rogue UAS.

6. Artificial Intelligence (″AI") – Enable re-routing and de-confliction by integrating AI into the UTM system.

7. Airworthiness Certifications – Pursuant to BVLOS and night-time operations, it provides a broad criterion of airworthiness for manufacturers.

8. Commercial Operations of UAS – Enables transportation of bodily organs for emergencies, surveying of landscapes and active monitoring of rail/road traffic.

9. Foreign Direct Investment (″FDI") – 100% FDI under the automatic route in RPAS-based commercial civil aviation services, subject to the financial threshold applicable to non-scheduled air transport operators.

10. Insurance – Cover the liability towards the cargo, hull loss and third-party risks that may be possessed due to commercial and/or BVLOS operations of the UAS in compliance with the Carriage by Air Act, 1972 or any other applicable law.

11. Autonomous Operations – Pursuant to BVLOS, operators need not maintain control of the UAS, provided it is used for ethical purposes and subject to protection of security and privacy of human beings.

Global Positioning Systems: Global positioning systems play a key role in identification, location and navigation. These systems are reliant solely on the operation of satellites and transmission/ collection of data using such satellites.

The legislative framework surrounding the operation of satellites in India is currently lacking. India has ratified the 1967 Outer Space Treaty, 1968 Rescue Agreement, 1972

Liability Convention, and 1975 Registration Convention that govern the operation of satellites in outer space.

Despite such ratifications, no specified legislation has yet been enacted by the Indian legislation in this regard. The only legislations that are considered to constitute India′s policy framework with respect to the operation of satellites and handling of data generated in this regard are the SATCOM policy of 2000 and the Remote Sensing Policy of 2011. However, neither are applicable to satellite navigation.

The SATCOM policy of 2000 addresses policy implementation for nationwide satellite communications whereas the Remote Sensing Policy of 2011 establishes the modalities for permitting and/or managing remote sensing data acquisition to support development activities.

The data collected with respect to global positioning systems would be deemed as geospatial information under the draft Bill and any person or entity generating such geospatial information would be required to obtain a license to own or use such data.

Way forward: As is evident, there is a lack of a specific and concise legislation with respect to regulating the domain of geospatial information. The draft Bill was introduced in the right direction in 2016 but has not been worked upon further. At present, the regulation of geospatial technology is spread across various policy documents that often leads to a lot of confusion with respect to compliance for businesses operating in this business domain.

The regulation of geospatial technology and geospatial information is a multi-faceted domain which spills into many sectors including information technology, space technology, remote sensing, defence, and even aviation if we include drones. Therefore, any policy related to geospatial must be framed by an interdisciplinary group which has a clear understanding of what the technology means and entails.

Draft Geospatial Information Regulation Bill, 2016: In the light of gross misrepresentation of India′s international boundaries not only by some of our immediate neighbouring countries but also by a few powerful media houses, intelligence agencies of other countries, as well as by some world organisations, the Government of India felt the need to have a geospatial data and information regulation bill. The draft of the Geospatial Information Regulation Bill, 2016 circulated by the Ministry of Home Affairs, Government of India, to regulate the acquisition, dissemination, publication and distribution of geospatial information of India, contains many provisions which will adversely affect academic activities and economic interests. The immediate provocation for the bill is the misrepresentation of our international borders, especially with Pakistan and China. Though the intention of the bill is in the interest of the protection of the sovereignty and integrity of the country, the fact that the whole gamut of geospatial information is set to get into the Indian bureaucratic realm, reputed for ″redtapism,″ is what is worrisome.

We are over-secretive with our maps; not making them accessible in the internet for the use of students, researchers, scientists, academics and the like. Earth scientists mostly use maps produced by the Survey of India and the National Atlas and Thematic Mapping Organisation (NATMO). Maps produced by these organisations are used to derive other thematic maps. Thus, most of the maps that are generated by the earth scientists are redrawn maps. The most commonly used redrawn map is perhaps the India map to show location of a certain study area within India.

Control or Deter? Today maps have gone digital and global. People use the internet freely to borrow a map of India. As a result, maps of India with misrepresented international boundaries abound in various internet sources. This is where people are caught unawares. It has come to light that a couple of our neighbouring countries and a few international publishing and media houses insist on ″their version" of the map of India to be used, if a scientific or academic paper is to be published in their journal and/or site. That is the level of campaign some of India′s neighbours and a few international agencies have directed to bring misrepresented maps of India into circulation. No one doubts the need of the hour for this bill. However, the bill will serve to control only Indian citizens, instead of serving as a deterrent to others.

The crux of the proposed bill is the sweeping definition of ″geospatial information"—to include

geospatial imagery or data acquired through space or aerial platforms such as satellite, aircrafts, airships, balloons, unmanned aerial vehicles including value addition; or graphical or digital data depicting natural or man-made physical features, phenomenon or boundaries of the earth or any information related thereto including surveys, charts, maps, terrestrial photos referenced to a coordinate system and having attributes; ...

The definition is so thorough that it leaves nothing in the hands of map and remote-sensing data-users to go with, without the approval of the Security Vetting Authority (SVA). Fortunately, Indian governmental bodies have been left as exceptions to this regulation bill.

However, the draft bill in its present form will badly affect all academics teaching and researching in earth sciences. As it is, restrictions on topographic maps at scales 1:50,000, 1:25,000 produced by the Survey of India, which are utilised as ″base" maps not only for bringing remote-sensing data to a coordinate/ referencing system but also employed for an umpteen number of purposes, already exist. Restrictions on access to aerial photographs, other important tools in the kit of earth scientists are so tight, the less said the better. Accuracy and precision in geospatial data and information is scale-dependent. While tracing, redrawing or digitising smaller scales (smaller maps showing large areas), certain inaccuracies or omissions may take place. For instance, a crenulated boundary in a large-scale map (large maps showing small areas) can turn into a rounded, smooth line in a small-scale map.

Remote-sensing data came as a respite and the earth science community did a wonderful job using this data for a variety of purposes and the country benefit- ted. But the axe fell on remote-sensing data. High resolution remote-sensing data had been restricted leaving low- and medium-resolution data free for users. If this bill comes into play all types of data come within the ambit of ″restriction" and ″vetting."

The bill may be good in spirit, but in letter (if one looks at the definition of geospatial information), it does not augur well for the earth scientists and the country.

Contours of a Bill: Maps, aerial photographs and satellite- based, remote-sensing data are the tools of earth scientists and this bill takes away the most important tools left in the kit of earth scientists to go about their job. How do we know what to do with our most precious asset—our land—if we do not know how our land looks like? This bill in its present form will restrict earth scientists in our country from making updated, competent maps, thus bringing about economic ramifications for the country. It is not just

government organisations that generate geospatial information. Substantial and significant contributions come from academic institutions at less than half the actual cost the government organisations spend. We are poor producers and users of maps and atlases. With the result we have a scarcity of maps, especially of India in the country. This would discourage and deter small- to medium-sized business- es from producing maps which are used everywhere, from schools to universities. Moreover, the cost of map production would increase because of fee levies and charges to obtain permissions from SVA.

The bill talks about misrepresentation of topography. Topography in glacial areas (our boundary passes through many glaciers), large riverine plains and deltas (Ganga–Brahmaputra–Meghna), large tidal and salt flats (along coastal Indo–Bangladesh and Indo–Pakistan borders) is highly dynamic and it is a challenge to obtain the updated, competent maps. In such cases of changing topography, misrepresentation of topography cannot be ruled out.

Keeping the spirit aside, if one has a look at the letters of the bill, two aspects of geospatial information stand apart— one, the data, which means the maps made by various organisations; the other being remote-sensing data acquired by our country. From these maps and remote-sensing data, ″information" is extracted through various methods. This information extraction is both a technical and intellectual activity and mistakes can occur here; but, who will judge this information? Would a joint secretary be competent enough or would it be a technical or a national security expert? In difficult situations the judgment will move to the SVA now and in most of the cases of geospatial information, it would be a ″no" from SVA because there is a fear factor playing in. It would then be excruciating for producers of information to follow through such situations, which are more likely to be common than exceptions. After all, the question is one of political boundaries, and rigour must be applied so that misrepresentations do not enter the public digital domain.

From the security point of view, coordinates of locations and the remote- sensing data that facilitate the making of three dimensional models of topography are important. Remote-sensing technology is available with many countries. Fortunately, the political boundaries do not extend into space. Space, from where one can peep into other countries, is free for all. Remote-sensing data are available for a price—and for no price also—in several countries and organisations. When data is available so freely from several other sources, restrictions on acquiring data for our own scientists and the academic institutions are meaningless. Withholding of data and information dissemination are two totally different aspects. Dissemination of wrong information must not be allowed; it must be punished. However, withholding data of certain kind should be freed from this bill.

Connecting the Dots: From the mid-1970s an enormous amount of remote-sensing data had been acquired by academic institutions, teachers and researchers and an equally enormous amount of information had been generated. What the bill will end up doing will amount to asking every person who has already acquired any remote-sensing data to process an application in order to retain it. Other than the obvious implications this will have to many people as well as institutions, this will also mean that the SVA itself would drown under the deluge of sifting through this task alone.

A geospatial data and information regulation bill is a necessity; but not with all the provisions as proposed in the draft of the Geospatial Information Regulation Bill, 2016.

There are already restrictions on maps and aerial photos and high resolution 2D and stereo remote-sensing data along international boundaries and around strategic areas and installations. The data recorded by satellite/aerial sensors/cameras do not lie, nor do they misrepresent. Instead, it is suggested that the data be left free, while restrictions be imposed on the information extracted. If at all there have to be restrictions, they ought to be limited to very high resolution 2D and 3D remote-sensing data of 1m and sub-metre pixels, and not on medium and high resolution 2D and 3D remote-sensing data.

To avoid the problem of misrepresentation of our international boundaries, the simplest solution lies in uploading authenticated (authenticated, perhaps, by Survey of India with a watermark seal certification) maps of India at various scales and in various software formats. The punishments proposed in the bill for wrong depiction of boundaries of India are welcome, but, we believe, too harsh.

Finally, the intention of the map-maker/ user should be factored into the question of legality and illegality. Though the provision of punishments may make the citizens of India a little more conscious now about representation of international boundaries, there is no mechanism to stop intentional misrepresentation by non-Indians. Having said this, it must also be added here to the powers that be that a healthy academia does not flourish under the shackles of draconian restrictions but on freedom.

How it will affect industry & growth: Geospatial Information today is not limited to Survey of India or Google Maps. Modern innovative technologies like Building information Modelling, Internet of Things, Cloud computing, Big Data analytics, mobile commerce, autonomous vehicles, and social media are all location-dependent.

Going by this Bill, use of any of these business processes not only has to seek clearance for generating geospatial information but also seek licenses for every value addition. And in case a license is rejected, the unique intellectual property of the innovator has to be destroyed.

Mathur points out geospatial technologies would power several mega projects of the government like Smart Cities, Digital India, Clean Ganga Mission, Swachh Bharat Abhiyan, roads and highways, among others. Hence, it is imperative that geospatial information products like maps, imageries, aerial photographs, etc. are made available to all those who can benefit from them. Aiyar feels if access to data is compromised, even initiatives like Skill India and Start-Up India will fail. The Bill in its current form is sure to discourage start-ups who would require licence and clearances for each and every update or value addition made, as also investments into location-based services critical for national growth.

The larger losses would be map users in navigation space like in automobiles and services related to them.

Interestingly, ISRO′s successful completion of the IRNSS constellation was being touted as a huge opportunity for India to come up as a low-cost, high-skill manufacturing hub for GNSS sensors and other related hardware and software. The Bill is sure to severely impact any such plans.

How it affects research & innovation: Under open data policy, coarse and moderate resolution data is available for carrying out research and societal application. Many datasets like MODIS and NOAA are not even available from ISRO. Since the Bill restricts acquisition of any kind of spatial data by anyone, a researcher cannot download

any satellite images of any resolution, thematic maps or other spatial content of India which are available free of cost on the Internet. More than 99% students use open source data — usually with resolution between 20 m to 1 km available globally — for their practical and project works.

Besides, many satellite data provide information like soil moisture, land/sea surface temperature, greenhouse gases, polar ice and many such parameters. Non-availability of these datasets will practically kill any innovation in this space. A researcher in geospatial information, environmental and climate science will now need a license with a requisite fee (not known) for the acquired satellite images and thematic maps for their degrees. Thus, in essence they are being denied the IPR for the value addition that they have done on openly available spatial data. Also, if the license application is rejected, researchers need to destroy that information which is otherwise their IPR.

Researchers in geospatial science cannot publish their papers in any international journal or make presentations at international conferences/seminars/workshops outside India without license and clearance. An individual carrying out innovative research will have to wait for clearance which can take months to years. By that time his research will be irrelevant.

The way forward: Geospatial is a multidisciplinary activity which spills into or borrows from many areas including IT, space technologies, remote sensing, defense, and even aviation if we include drones etc. Therefore, any policy related to geospatial must be framed by an interdisciplinary group which has a clear understanding of what the technology means and entails. In this case, the very wordings of the Bill makes it obvious that MHA committee that drafted it did not have a sufficiently interdisciplinary group with clear understanding about how geospatial data is created and used.

Forget about involving in drafting, the immediate controversy the Bill generated even from within the government departments — though no one will go on record on this — is clear enough to indicate that the draft was not even circulated among the members of the Committee of Secretaries (CoS). The CoS includes the Secretary DST and the reaction from DST was knee-jerk to say the least.

While Dr Swarna Subba Rao, Surveyor General of India, responded by saying his office was currently examining the draft law (thus exposing how collaborative the MHA efforts have in if the Surveyor General of the country has to read a draft law on maps after its release in public domain!) a DST spokesperson had gone on record saying the Bill will be drastically modified, the penalties reduced and mainly target specific companies that ″wrongly depict borders.″

There is no doubt that the existing version of the Bill will be ″significantly changed″ as it ″goes against the spirit″ of the National Geospatial Policy, 2016, spearheaded by the DST. The official also said that DST forwarded its inputs to MHA who acknowledge the same but are silent about its future actions. It will be at least two years before it could become law, the spokesperson said, thus indicating inter-departmental opposition to this Bill. A clear cut law on geospatial information and sharing is welcome. India does need a law in this field spelling out clarity. And the numerous policies in this field that the successive governments keep flaunting are not enough. A policy is not mandatory, a law is. But any law must have an understanding of ground realities, must be open and encouraging for industry and users.

MODULE-VI

ISSUES AND TRENDS IN GIS TECHNOLOGIES

MODULE-VI: ISSUES AND TRENDS IN GIS TECHNOLOGIES

Implementation Issues and Strategies: This part presents an overview of implementation issues and requirements. The focus is on identifying implementation planning issues and strategies that must be addressed for a successful GIS implementation.

- Current Options and Software Assessment
- Justification and Expectations
- Implementation Issues

Current Options and Software Assessment:Perhaps the first question asked by anyone when discovering GIS is what are the current options available ?. This question is often asked as directly as what is the best GIS ?. Quite simply, there is no best GIS. A wide variety of GIS software offerings exist in the commercial market place. Commercial surveys often are a good starting point in the assessment of GIS software. The number of GIS software offerings is approximately 10 if one eliminates the following:

- the university based research software, which tends to lack full integration and usually has narrow channels of functionality;
- the CAD vendors, who like to use GIS jargon but often cannot provide full featured functionality; and
- the consulting firms, that will provide or customize selected modules for a GIS but lack a complete product.

One of the problems in evaluating the functionality of GIS software is the bias one gets from using one system or another. Comparing similar functions between systems is often confusing. Like any software, ultimately some do particular tasks better than others, and also some lack functionality compared to others.

Due mostly to this diverse range of different architectures and the complex nature of spatial analysis no standard evaluation technique or method has been established to date.

Any GIS should be evaluated strictly in terms of the potential user's needs and requirements in consideration of their work procedures, production requirements, and organizational context ! The experienced GIS consultant can play a large and valuable role in the assessment process. A current accepted approach to selecting the appropriate GIS involves establishing a benchmark utilizing real data that best represents the normal workflow and processes employed in your organization.

The identification of potential needs and requirements is essential in developing a proper benchmark with which to evaluate GIS software packages. A formalized user need analysis is absolutely critical to the successful implementation of GIS technology.

Development of the benchmark should include a consideration of other roles within your organization that may require integration with the GIS technology. A logical and systematic approach as such is consistent with existing information systems (IS) planning methodologies and will ultimately provide a mechanism for a successful evaluation process.

Justification and Expectations: GIS is a long term investment that matures over time. The turnaround for results may be longer term than initially expected. Quite simply, GIS has a steep learning curve. The realization of positive results and benefits will be not

achieved overnight. Both initial investments funding and continued financial support are major determinants in the success or failure of a GIS. Most often the justification and acquisition of a GIS centers on technical issues of computer hardware and software, functional requirements, and performance standards. But experience has shown that, as important as these issues may be, they are not the ones that in the end determine whether a GIS implementation will succeed or not.

Even though the proper assessment of an appropriate GIS product requires a good understanding of user's needs, most often systems are acquired based on less than complete and biased evaluations. Nonetheless, even with the GIS in hand a properly structured and systematic implementation plan is required for a successful operation. Generally, a GIS implementation plan must address the following technical, financial, and institutional considerations:

- system acquisition tactics and costs;
- data requirements and costs;
- database design;
- initial data loading requirements and costs;
- system installation tactics, timetable, and costs;
- system life cycle and replacement costs;
- day-to-day operating procedures and costs;
- staffing requirements and costs;
- user training and costs; and
- application development and costs.

Potential GIS buyers should be aware of the necessary investment required in hardware, software, training, supplies, and staffing. The cost of establishing a successful GIS operation is substantial. However, with realistic expectations and support the development of GIS within an organization that manipulates geographic data will almost certainly prove beneficial. Certain considerations of data longevity, data capture, personnel hiring, etc. are the practical concerns of GIS implementation. The longer term implications, such as hardware/software maintenance and replacement, should also be considered. The acquisition of GIS technology should not be done without seriously considering the way in which GIS will interact with the rest of the organization.

It is simply not enough to purchase a computer, a plotter, a display device, and some software and to put it into a corner with some enthusiastic persons and then expect immediate returns. A serious commitment to GIS implies a major impact on the whole organization.

Implementation Issues: The mere presence of an implementation plan does not guarantee success. Most organizations do not have sufficient staff to cope with the commitment and extra work required when introducing a GIS to existing operations. GIS implementation must also consider all technology transfer processes.

Common Pitfalls

Several pitfalls exist that most often contribute to the failure of a GIS implementation strategy. These are identified below:

***Failure to identify and involve all users*:** Users in an operational GIS environment consist of operations, management, and policy levels of the organization. All three levels should be considered when identifying the needs of your users.

Failure to match GIS capability and needs: A wide spectrum of GIS hardware and software choices currently exist. The buyer is presented with a significant challenge making the right choice. Remember, the right choice will be the GIS that provides the needed performance no more, no less for the minimum investment. The success of a GIS implementation is particularly sensitive to the right hardware and software choices !

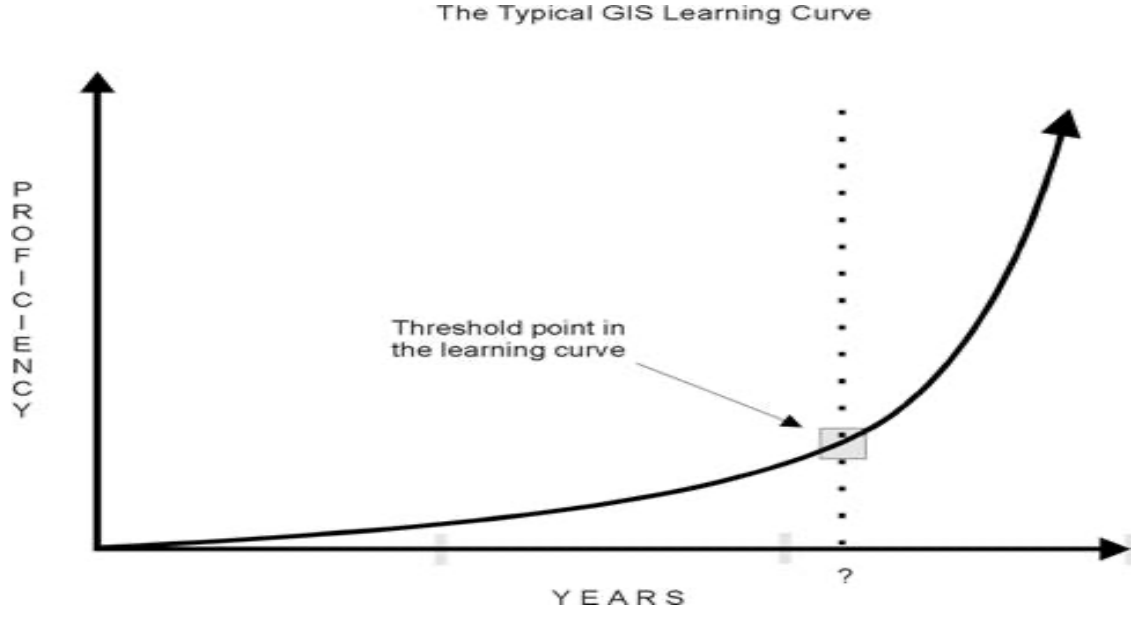
Failure to identify total costs: The GIS acquisition cost is relatively easy to identify. However, it will represent a very small fraction of the total cost of implementing a GIS. Ongoing costs are substantial and include hardware and software maintenance, staffing, system administration, initial data loading, data updating, custom programming, and consulting fees.

Failure to conduct a pilot study: The GIS implementation plan concerns itself with the many technical and administrative issues and their related cost impacts. Three of the most crucial issues, are database design, data loading and maintenance, and day-to-day operations. The pilot study will allow you to gather detailed observations, provided it is properly designed, to allow you to effectively estimate the operational requirements.

Giving the GIS implementation responsibility to the EDP Department: Because of the distinct differences of the GIS from conventional EDP systems, the GIS implementation team is best staffed by non-data processing types. The specialized skills of the 'GIS analyst' are required at this stage. Reliance on conventional EDP personnel who lack these skills will ensure failure.

Failure to consider technology transfer: Training and support for on-going learning, for in-house staff as well as new personnel, is essential for a successful implementation. Staff at the three levels should be educated with respect to the role of the GIS in the organization. Education and knowledge of the GIS can only be obtained through on-going learning exercises. Nothing can replace the investment of hands on time with a GIS !

The Learning Curve: Contrary to information provided by commercial vendors of GIS software, there is a substantial learning curve associated with GIS. It is normally not a technology that one becomes proficient in overnight. It requires an understanding of geographical relationships accompanied by committed hands-on time to fully apply the technology in a responsible and cost effective manner. Proficiency and productivity are only obtained through applied hands on with the system ! GIS is an applied science. Nothing can replace the investment of hands-on with GIS. The following figurepresents



the typical learning curve for GIS installations.

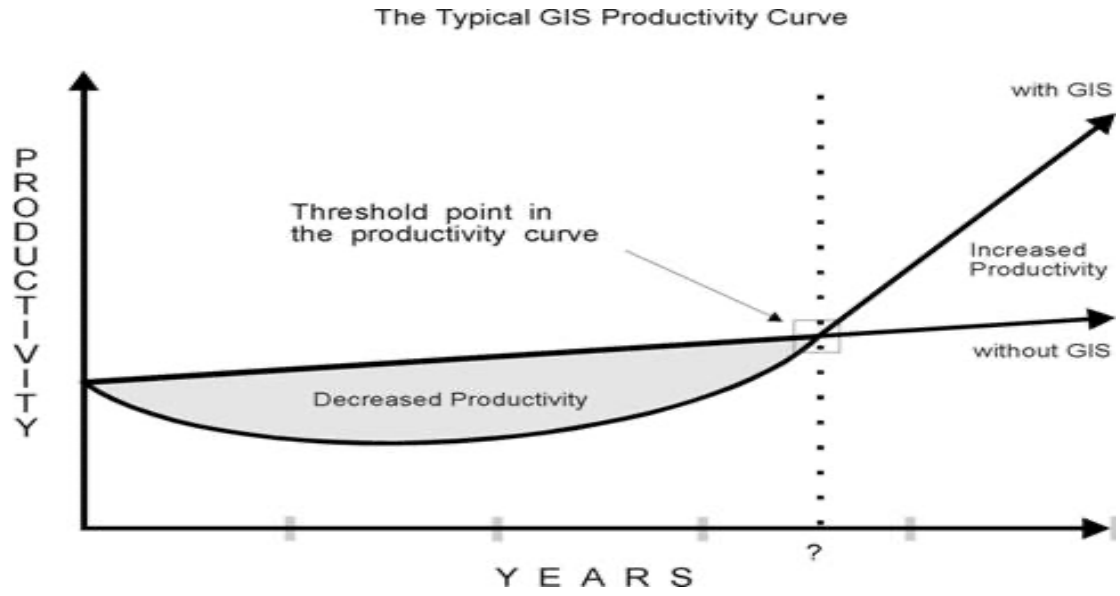
The learning curve is dependent on a variety of factors including:

- the amount of time spent by the individual with hands-on access;
- the skills, aptitude and motivation of the individual;
- the commitment and priority attached to GIS technology dictated by the organization and management;
- the availability of data; and
- the choice of software and hardware platforms.

A critical requirement for all GIS implementations is that adequate education and training is provided for operational staff, as well as realistic priorities are defined with which to learn and apply the technology. This is where a formal training curriculum is required to ensure that time is dedicated to learning the technology properly. Adding GIS activities to a staff member's responsibilities without establishing well defined milestones and providing adequate time and training mechanisms is prone to failure. A focused and properly trained operations staff that has consistent training will result in greatly reduced turnaround times for operations, and ensure consistency in quality of product.

The threshold point of the learning curve is typically around the two year time frame. However, this is dependent on the ability of the organization to establish a well defined and structured implementation plan that affords appropriate training and resources for technical staff. The flat part of the learning curve can be shortened if proper training is provided, data is available for use, the right software and hardware is acquired. The typical learning curve reflects a long initial period for understanding spatial data compilation requirements and database architecture. However, after data models are well understood and sufficient data compilation has been completed the learning curve accelerates. Once a formal application development environment is established and user needs are well defined an infrastructure exists for effective application of the technology. Building operational applications based on formal functional specifications will result in continued accelerated learning. The data hurdle is often a stumbling block for many GIS users.

The Productivity Curve: GIS is a long term investment that matures over time. The turnaround for results may be longer than initially expected. The establishment of a formal implementation strategy will help to ensure that realistic expectations are met. Data is the framework for successful application of GIS technology. In this respect, the investment in establishing a solid data platform will reap rewards in a short term timeframe for establishing a cost-effective and productive GIS operation. The availability of quality data supplemented by a planned implementation strategy are the cornerstones of achieving a productive and successful GIS operation. A robust database should be considered an asset!



However, even with a well defined and systematic implementation strategy GIS technology will not provide immediate benefits. Benefits and increased productivity are not achieved overnight. GIS technology is complex in nature, has a generally steep learning curve, and requires a complement of skills for it to be applied successfully. In fact, most organizations realize a loss in overall operational productivity over the short term while the GIS platforms are being installed, staff is trained, the learning curve is initiated, and data is being captured. This is common of all office automation activities. The following figure presents the typical situation that occurs with respect to comparing long term productivity with, and without, GIS technology.

This graph represents the typical situation that occurs with respect to comparing long term productivity with, and without, GIS technology.

Depending on the unique circumstances of the implementation process, the status of data compilation, and the organizational climate, increased productivity is normally reached between the second and fifth year of implementation. This is identified by the threshold point. Again, this is dependent on a variety of factors including:

- The skills and experience of the staff involved;
- The priority and commitment by the organization;
- The implementation strategy; and
- The status of data compilation.

The primary issue with implementing GIS is to achieve the threshold point of increased productivity in the shortest possible time frame. In other words, minimize the time in which a decrease in productivity occurs. Of course, the issue of productivity is typically of greaterst concern with private industry, e.g. forestry companies. Nonetheless, the significant investment in hardware/software, data, and training necessitates that a structured approach be utilized to achieve the threshold point in the shortest possible time frame. A GIS acquisition based on well defined user needs and priorities is more likely to

succeed than without. A major pitfall of most installations with GIS technology, e.g. particularly forestry companies and government agencies, is the lack of well defined user needs on which to base the GIS acquisition and implementation.

The Implementation Plan: Implementation can be seen as a six phase process. They are:

Creating an awareness: GIS needs to be sold within an organization. The education of staff is very important. Depending on the way in which GIS technology is being introduced to the organization the process for creating an awareness may differ. Technical workshops are often appropriate when a top-down approach exists, while management workshops are often more relevant when a bottoms-up approach exists. Education of the new technology should focus on identifying existing problems within an organization. These often help justify a GIS acquisition. They include :

- spatial information is poorly maintained or out of date;
- spatial data is not recorded or stored in a standard way;
- spatial data may not be defined in a consistent manner, e.g. different classifications for timber information;
- data is not shared between departments within an organization;
- data retrieval and manipulation capabilities are inadequate to meet existing needs; and
- new demands are made on the organization that cannot be met with existing information systems.
- Identifying System Requirements

The definition of system requirements is usually done in a user needs analysis. A user needs analysis identifies users of a system and all information products required by those users. Often a prioritization of the information products and the data requirements of those products is also undertaken. A proper user needs analysis is crucial to the successful evaluation of GIS software alternatives. After user needs have been identified and prioritized they must be translated into functional requirements. Ideally, the functional requirements definition will result in a set of processing functions, system capabilities, and hardware requirements, e.g. data storage, performance. Experienced GIS consultants often play a major role in this phase.

System Evaluations: Evaluating alternative hardware and software solutions is normally conducted in several stages. Initially a number of candidate systems are identified. Information to support this process is acquired through demonstrations, vendor literature, etc. A short listing of candidates normally occurs based on a low level assessment. This followed by a high level assessment based on the functional requirements identified in the previous phase. This often results in a rating matrix or template. The assessment should take into account production priorities and their appropriate functional translation. After systems have been evaluated based on functional requirements a short list is prepared for those vendors deemed suitable. A standard benchmark, as discussed earlier, is then used to determine the system of choice.

Justifying the system Acquisition:The proper justification of the chosen system requires consideration of several factors. Typically a cost-benefit analysis is undertaken to analyze the expected costs and benefits of acquiring a system. To proceed further with acquisition the GIS should provide considerable benefits over expected costs. It is important that the identification of intangible benefits also be considered. The justification process should also include an evaluation of other requirements. These include data base development requirements, e.g. existing data versus new data needs and associated costs; technological

needs, e.g. maintenance, training, and organizational requirements, e.g. new staff, reclassification of existing job descriptions for those staff who will use the GIS.

System Acquisition and Start Up: After the system, e.g. hardware, software, and data, is acquired the start up phase begins. This phase should include pilot projects. Pilot projects are a valuable means of assessing progress and identifying problems early, before significant resources have been wasted. Also, because of the costs associated with implementing a GIS it is often appropriate to generate some results quickly to appease management. First impressions are often long remembered.

Operational Phase: The operational phase of a GIS implementation involves the on-going maintenance, application, and development of the GIS. The issue of responsibility for the system and liability is critical. It is important that appropriate security and transaction control mechanisms be in place to support the system. A systematic approach to system management, e.g. hardware, software, and data, is essential.

GIS Technology Today: Today, Geographic Information Systems (GIS) and spatial analysis are being used by everyone whether we realise or not. Have you noticed that location-based search facility in Google? Do you use an app on your phone to get you from A to B? Do you track your parcel delivery or the taxi you booked? All these examples use spatial information to get you the best answer or the most up to date information.

Other examples include:

- Potential store locations - based on customer locations, customer spending power, route-time analysis, competitor locations.
- Predictive crime analysis - using GIS and spatial analysis resulted in 19 per cent reduction in break ins.
- Real time fleet tracking - reducing delivery costs by 10 per cent.
- Europe's busiest port - 370 vessels per day - helping Dutch infrastructure to rate #1 in the world.
- Air quality - better informed environmental and health policy for Europeans.

Rooted in the science of geography, modern GIS integrates many types of data. It analyses spatial location and organises layers of information into visualisations using maps and 3D scenes. With this unique capability, GIS reveals deeper insights into data, such as patterns, relationships and situations - helping users make smarter decisions. Hundreds of thousands of organisations in virtually every field are using GIS to make maps that communicate, perform analysis, share information and solve complex problems around the world. This is changing the way the world works. The Geographic Information System market is predicted to reach US$9billion by 2024* (*Report by Global Market Insights 2024).

Tackling the big data challenge: A number of years ago, the hype was around ′big data and the challenge of how we were going to be able to cope with reams of data. It could be argued that GIS has been dealing with ′big data for years. Satellite imagery, orthophotography, largescale mapping and LIDAR point clouds all create gigabytes of data. These days, combining GIS with geospatial cloud platforms and the improvements in computing power are enabling businesses to analyse massive warehouses of information. The results of this analysis often expose new data patterns and inspires innovative ways to increase success through the understanding of location intelligence. But, rather than spitting out piles of stats, tables, charts and spreadsheets, the geospatial

cloud empowers people to plot complex analysis on easy-to-understand smart maps. These digital maps allow leaders, strategists and many levels of workers to visualise vital trends across lines of business and take decisive action in mission critical projects.

GIS and the maps created for organisations become even more important when linked to the huge data streams from the Internet of Things (IoT), allowing real time monitoring of trends. The location intelligence derived from these streams of information when combined with AI and predictive analytics can map out ways to drive productivity or adjust strategies to keep businesses on track to succeed.



Figure 1: GIS allows local government to make funding and allocation of labour decisions based on real time data. Here are examples of homeless shelters and occupants in the Washington DC area.

Tracking the movements of life: Modern GIS allows people to create map visualisations that represent thousands of relationships between hundreds of layers of data on demographics, sales, population growth, traits of customers, likely customers, competitors, supply chains, delivery routes and countless other variables. The results can be modelled in 3D to support the work of urban planners and facilities managers, who can also benefit from data streaming from the IoT for real-time updates to their models and maps. With open platforms to stimulate innovative applications, it′s hard to summarise the richness of the tools and growing power of the geospatial cloud. But, its influence can be seen in the thousands of leading businesses using it to analyse millions of layers of data and produce billions of maps every day.

Geospatial cloud grows in strength, flexibility and accessibility: Increasingly, corporate leaders are realising that intelligent maps provide an effective way to monitor sales, review assets in the field, keep up to date on national and global social and economic trends -reinforcing common goals across all departments. The flexibility of tools, apps

and data available in the geospatial cloud puts its power within reach of everyone in an organisation. Whether employees rely on company servers, desktop computers, laptops, tablets or smartphones, whether they work in the corporate office or are mobile and remote, they can all connect. Such widespread accessibility protects against information silos and allows for wider sharing of knowledge across the organisation.

Utilising instant tools: Drawing upon analytic models, predictive algorithms, apps and big data, detailed insights can emerge through computerised analysis of layers of data on customers past buying history along with their demographics by neighbourhood and their interests by age, gender, education or profession. It can also factor in larger trends like local economies, seasonal weather, time of day and national or international political and social trends. At the broader other end of the scale, smart maps receiving data from sensors on the IoT allow company analysts see trends mapped out in real time. The visualised location intelligence can show buying trends, population shifts or traffic patterns that affect deliveries, supply chains, asset management and research and development, and take into account trends across hundreds of layers of demographic, economic and political data.

Span of influence of the geospatial cloud: Though vital to the for-profit sector, the power of the geospatial cloud is not the sole province of private business and industry. Widely available free or low-cost spatial data and systems also help most national, state and local governments' map critical issues from health to crime to utility lines and even to eradicating land mines. And it underpins the work of non-governmental organisations around the world - groups helping to solve environmental issues, address social justice concerns and develop mission-focused, crisis-response strategies for hurricanes, earthquakes or epidemics.

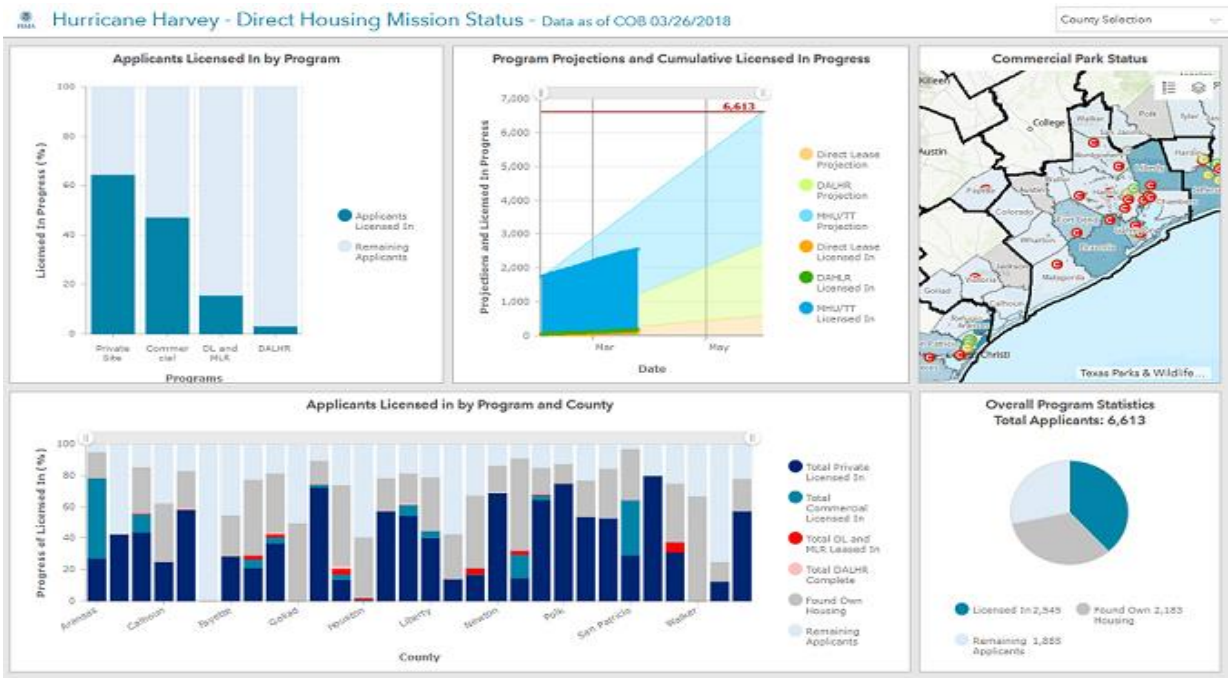


Figure 2: Tourist areas can assess the flow of visitors at key attractions and resources can be applied to areas of greater need.

For example, applications can take ongoing satellite imagery and current weather and temperature data to build a Living Atlas - a real-time picture of the world that shows permanent land masses, changing polar caps, epidemics, rising or falling wages and trends in local agriculture or regional social culture.



Figure 3: Managing emergencies and acts of God. Here, regional data reflects the dispossessed population and housing need and fulfilment following Hurricane Harvey.

Location-based information can also shape many policy decisions and help people across the political spectrum understand issues and options. The geospatial cloud offers scalable analysis from a single building to a neighbourhood to a town, state, nation, continent, or the entire globe.

GIS keeps evolving and adding depth : Broad in reach and deep in analytic power, the geospatial cloud can engage the minds and spirits of millions around the world through a project like the Esri Living Atlas. Applications also can be developed that engage people around the world in mission-driven campaigns and social enterprise. Volunteers can work together to track worrisome trends and businesses can use location-based data and predictive apps to understand what consumers will want and need several years from now.

The geospatial cloud introduces a new scale of spatial intelligence and businesses and organisations of every size and purpose are using it to break new ground and digitally transform their enterprises.

Development and Trends in GIS: This part reviews the upcoming trends in GIS technology in -

- New Data sources
- Hardware Developments
- Software Developments

The development and application of geographic information systems is vibrant and exciting. The term GIS remains one of the most popular buzz words in the computer industry today. GIS is perceived as one of the emerging technologies in the computer marketplace. The involvement of major computer vendors is an illustration of this fact. Everybody wants a GIS. This popularity is not without its validity however. GIS is very much a multi-disciplinary tool for the management of spatial data. It is inherently complex because of the need to integrate data from a variety of sources. Functions must accommodate several application areas in a detailed and efficient manner. A variety of important developments are occurring which will have profound effects on the use of GIS. They are identified in the following sections.

New Data Sources: The generation of data from new sources is an on going development. Application specialists have traditionally attempted to research and implement new data sources into their work. Most of these new data sources are based strictly on scientific technological developments.

Remote sensing will become, if it is not already, the primary source for new data. Due to recent technological developments in hardware most GIS software can now accommodate remotely sensed imagery at high resolutions, and in varying formats. Remote sensing data can include aerial photographs, satellite imagery, radar imagery, etc. Some of the past problems with using remotely sensed imagery have been the inability to integrate it with other data layers, particularly vector encoded data. Remote sensing specialists stress that their data is of most value when combined with, and substantiated by, other data sources. Several commercial GIS products are now offering their software bundled with an image processing software package. Many of these packages allow you to interactively view data from both systems simultaneously, and also afford the conversion of data between systems. The integration of GIS and image processing capabilities offers a great potential for resource specialists.

Another data source that has generated much interest is **Digital Elevation Models (DEM)**. Elevation data has traditionally been generated from the interpolation of contour information. However, recent technological developments and the establishment of several digital mapping projects by government agencies has propagated the use of and interest in elevation modelling. Several different sources of DEM data exist within Canada. The most common and readily available DEM data can be acquired from either the federal government, e.g. 1:250,000 map scale, or from selected provincial government agencies. For example, DEM data commensurate with a 1:20,000 map scale is distributed by the Alberta Government under the 1:20,000 Provincial Digital Mapping project. In British Columbia, DEM data is available with the 1:20,000 TRIM project. In both these cases DEM data is captured photogrammetrically during the stereo-compilation phase of the topographic data capture process. Each DEM is comprised of X,Y, and Z coordinates at regular intervals across a map sheet. This regular grid is supplemented by spot height data points and breakline information (irregular points). In the United States, DEM data is

available from a variety of sources, however the most common is the USGS (United States Geological Survey) 1:24,000 QUAD sheets.

DEM data can be used in the generation of a variety of data derivatives. The most common are slope and aspect. The ability to integrate DEM data is a common function within most GIS packages. However, it is typically offered as a separate module that must be purchased individually.

Hardware and Software Developments: The technological advancements made in hardware and software development over the past few years have been phenomenal. The distinction between personal computer and workstation, a mainstay during the 1980's has become very fuzzy. Recent developments within the micro-chip industry, e.g. the Pentium chip, have made the micro-computer a viable and promising tool for the processing of spatial data. Most notable of these is the emergence of 32-bit Pentium chip micro-computers and the use of the Windows NT operating environment.

Several trends in hardware and software development for GIS technology stand out. These are reviewed below:

- The dominant hardware system architecture for GIS systems during the 1980's was the centralized multi-user host network. The distributed network architecture, utilizing UNIX based servers, and desktop workstations, has been the norm over the past five years.;

- The trend in disk storage is towards greatly increased storage sizes for micro-computers, e.g. PC's and workstations, at a lower cost;

- The emergence of relatively low cost reliable raster output devices, in particular inexpensive ink jet based plotters, has replaced the more expensive color electrostatic as the ad hoc standard plotting device for GIS.;

- The emergence of fast, relatively inexpensive micro-computers with competitive CPU power, e.g. 32-bit Penitum has challenged the traditional UNIX stronghold of GIS.;

- While the de facto operating system standard has been UNIX , the Windows NT operating system is emerging as a serious and robust alternative. This is especially prevalent with organizations wishing to integrate their office computing environment with their GIS environment. This trend is closely associated with the development of 32-bit micro-computers.;

- SQL (Standard Query Language) has become the standard interface for all relational DBMS;

- The ability to customize user interfaces and functionality through Application Programming Interfaces (API) and macro languages. The major development in GIS technology over the past five years has been the ability to customize the GIS for specific needs. Application development is a mandatory requirement for all GIS sites, and should be weighted accordingly when considering a GIS acquisition.

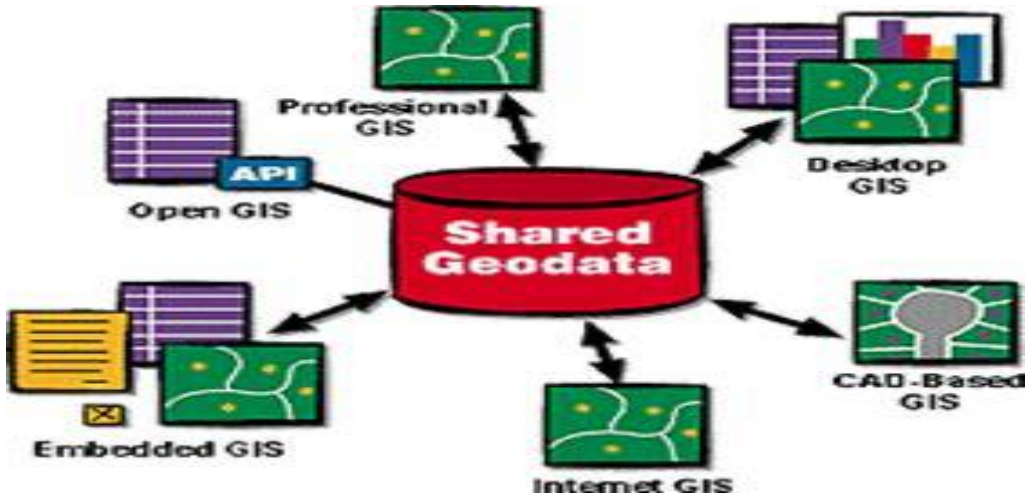


Fig: Increasingly GIS are using a shared geo-database structure to integrating all the different data now available.

Some GIS Technology developments: In the 1960s, computer based GIS concepts began to be explored in North America and today numerous and considerable technological and methodological developments have taken place in the field of GIS. The main advancements are a result of the use of computing techniques and this would continue to affect the future advancements also.

Some of the important developments in GIS methodology are listed below:

- GIS has evolved from the earlier use in mainframe computers to personal computers to now in mobile devices, facilitating the growth of GIS usage and research
- application of computer based technology to handle numerical census data for deriving useful information
- introduction of topological data structures to store and analyse map data
- relational database technology becoming standard and integral part of GIS for handling spatial/aspatial data with the development of spatial database management systems (SDBMS)
- standardisation of data quality norms and accuracy standards
- developments in the field of object orientation in system and database design
- advent of internet and subsequent developments of GIS tools in World Wide Web leading to development of new internet protocols, easy to use interfaces (browsers), tools and programming languages, Web GIS, OPEN GIS, etc
- evolution of GIS from a mere powerful spatial technological tool to a spatial science
- it was earlier required to have all the parts at one place for any GIS implementation; whereas its now possible to access data and software remotely and implement
- its applications have expanded from mapping and resource management to utilities, market analysis, location based service and data browsing

- use of GIS has now opened up for general public from the earlier restricted use in only government sectors
- focus has changed from earlier system centric approach to service oriented approach

3D GIS

The land surface has been the object of mapping for hundreds of years and the terrain with its undulating, continuous land surface is a familiar phenomenon to GIS users. Mapmakers have introduced various techniques for displaying 3- dimensional Earth into 2-dimensional maps and GIS outputs which has made it easier to incorporate terrain mapping and analysis into applications ranging from wildlife habitat analysis to hydrologic modelling. Use of 3D in GIS began around a decade back. Now most of the GIS software has the capability to create 3D visualisation complete with landscape objects such as buildings, trees, etc. Fig. 1 displays the capability of 3D GIS in visualisation of features. At present, the 3D research area is concerned with issues of 3D structuring and 3D topology.



Fig.1: 3D GIS showing realistic landscape objects (source: www.esri.com/ mapmuseum/mapbook_gallery/volume24/engineering1.html)

Web GIS

The advent of web mapping can be regarded as a major new trend. Earlier, cartography was restricted as it required expensive and complex hardware and software, as well as skilled cartographers and geoinformatics engineers. With web mapping, freely available mapping technologies and geodata potentially allow every skilled person to produce web maps.

Web mapping is the process of designing, implementing, generating and delivering maps on the World Wide Web and its products. While web mapping primarily deals with technological issues, web cartography additionally includes theoretic aspects: the use of web maps, the evaluation and optimisation of techniques and workflows, the usability of web maps, social aspects, and more. Web GIS is similar to web mapping but with an emphasis on analysis, processing of project specific geodata and exploratory aspects (Fig. 2).

Often the terms web GIS and web mapping are used synonymously, even if they don′t mean exactly the same. In fact, the border between web maps and web GIS is blurry. Web maps are often a presentation media in web GIS and web maps are increasingly gaining analytical capabilities. A special case of web maps are mobile maps, displayed on mobile computing devices, such as mobile phones, smart phones, PDAs, GPS and other devices. If the maps on these devices are displayed by a mobile web browser or web user agent, they can be regarded as mobile web maps.



Fig:2 - Concept of WebGIS

There are various types of web maps, such as analytic, animated, collaborative, customised, distributed, hyper maps, interactive maps, etc. Out of which collaborative web map projects appear to be more popular, such as Google Map Maker, OpenStreetMap, WikiMapia, etc.

There are several advantages of web maps. We will mention here about some of them:

• *easy delivery of up to date information*- when the maps are generated automatically from databases, they can display information in almost real- time for example, a map displaying the traffic situation near real-time by using traffic data collected by sensor networks or a map showing locations of vehicles

• availability of software and hardware infrastructure at low cost • easy distribution of product updates

• webmaps work across browsers and operating systems

• capability to combine distributed data sources

• web maps allow for personalisation

• web maps enable collaborative mapping

• web maps support hyperlinking to other information on the web • easy to integrate multimedia with web maps.

Location Based Services (LBS)

Convergence of different technologies, such as wireless networks, internet, GIS and GPS have introduced a new type of information technology, called Location Based Services (LBS). It is developing rapidly in the mobile and IT fields. Advancement of LBS is governed by increased demand and interest in utilising geospatial information through wireless networks. LBS is an information or entertainment service, accessible with mobile devices through the mobile network utilising the ability to make use of the geographical position of the mobile device (Fig. 3). LBS can be used in a variety of contexts, such as health, indoor object search, entertainment, work, personal life, etc.

LBS include services to identify a location of a person or object, such as discovering the nearest banking cash machine or the whereabouts of a friend or employee. LBS include parcel tracking and vehicle tracking services. LBS can include mobile commerce when taking the form of coupons or advertising directed at customers based on their current location. They include personalised weather services and even location-based games. They are an example of telecommunication convergence. LBS applications are useful for the following tasks:

• recommending social events in a city

• requesting the nearest business or service, such as an ATM or restaurant

• turn by turn navigation to any address

• locating people on a map displayed on the mobile phone

• receiving alerts, such as notification of a sale on gas or warning of a traffic jam

• location-based mobile advertising

• games where your location is part of the game play, for example your movements during your day make your avatar move in the game or your position unlocks content.

• real-time questions and answers revolving around restaurants, services, and other venues.

Mobile messaging plays an essential role in LBS. Messaging, especially SMS, has been used in combination with various LBS applications, such as location- based mobile advertising. SMS is still the main technology carrying mobile advertising/marketing campaigns to mobile phones. A classic example of LBS applications using SMS is the delivery of mobile coupons or discounts to mobile subscribers who are near advertising restaurants, cafes, movie theatres. The Singaporean mobile operator MobileOne carried out such an initiative in 2007 that involved many local marketers, which was reported to be a huge success in terms of subscriber acceptance.

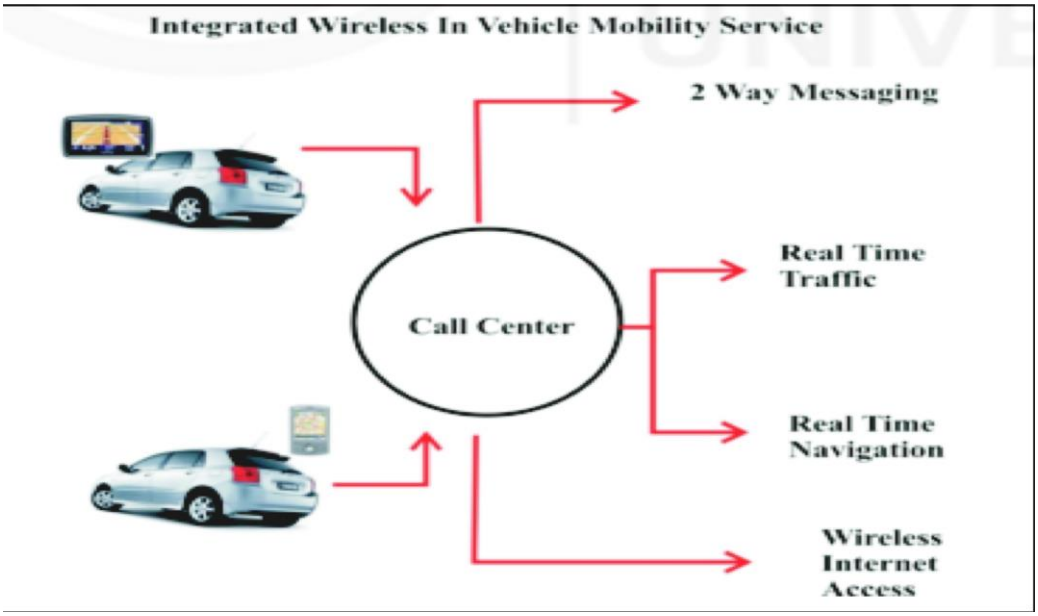


Fig:3 - An illustration of the concept of LBS

Mobile GIS

GIS is rapidly extending into the mobile environment also which is now known as Mobile GIS. Mobile GIS is the use of geographic data in the field on mobile devices. It integrates three essential components; Global Navigation Satellite Systems (GNSS), rugged handheld computers, and GIS software. Bringing these three technologies together make the enterprise database directly accessible to field personnel whenever and wherever it is required. Mobile GIS has an advantage over LBS. Location based systems require either you or at least your phone to be there to get location but it is difficult in some cases. Mobile GIS is useful in such cases.

Mobile GIS is a mapping technology for resource managers and other field workers to visualise and improve their field-based management and research tasks. With mobile GIS, field workers may capture spatial data directly in the field and, with access to a wireless communication network; the data can then be remotely transferred in real time to the central database back at the company office. Mobile GIS is especially important in emergency situations and natural disasters when emergency workers, such as fire-fighters (Fig. 4), need to have access to the most current and accurate information in order to make decisions about people′s lives and the health of the environment.

Fig:4 - Illustration of the concept of Mobile GIS



Enterprise GIS

Enterprise GIS is a geographic information system that is integrated through an entire organisation so that a large number of users can manage, share, and use spatial data and related information to address a variety of needs, including data creation, modification, visualisation, analysis, and dissemination. Concept and capabilities of Enterprise GIS is shown in Fig. 5.

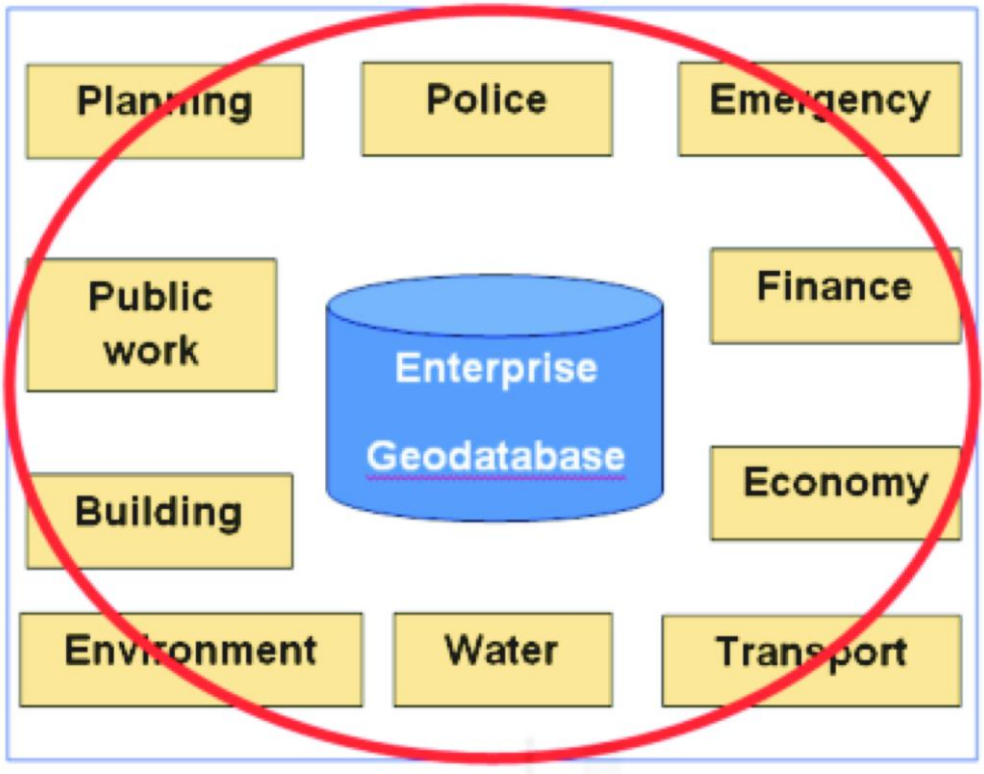


Fig. 5: Capabilities of Enterprise Geodatabase

Enterprise GIS has evolved over a period of time and especially during last five-six years. Most of the leading GIS vendors have had components that constitute an Enterprise GIS for long time but the efforts to have them all packaged together and provide an end-to-end solution picked up fast pace in the recent times. To put it in simpler terms, an Enterprise GIS should be capable of:

• supporting huge number of simultaneous transactions

• integrating with other Enterprise Systems (such as SAP, Billing Systems)

• comply with Open Geospatial Consortiums (OGC) Standards to enable easier integration with other systems

• displaying data in the same way (styles/symbols) for Desktop, Web and Mobile users

• preferred reusable functionality across Desktop, Web and Mobile platforms.

Some of the applications of Enterprise GIS are the following as shown in Fig. 6:

• increased communication and encouragement of collaboration among various organisational departments in support of better decision making

• lower cost of software ownership and increased return on investments through single, focused GIS applications (such as Web applications) that scale to support many users

• integration of GIS functionality with other enterprise systems in an effort to better manage resources and assets.

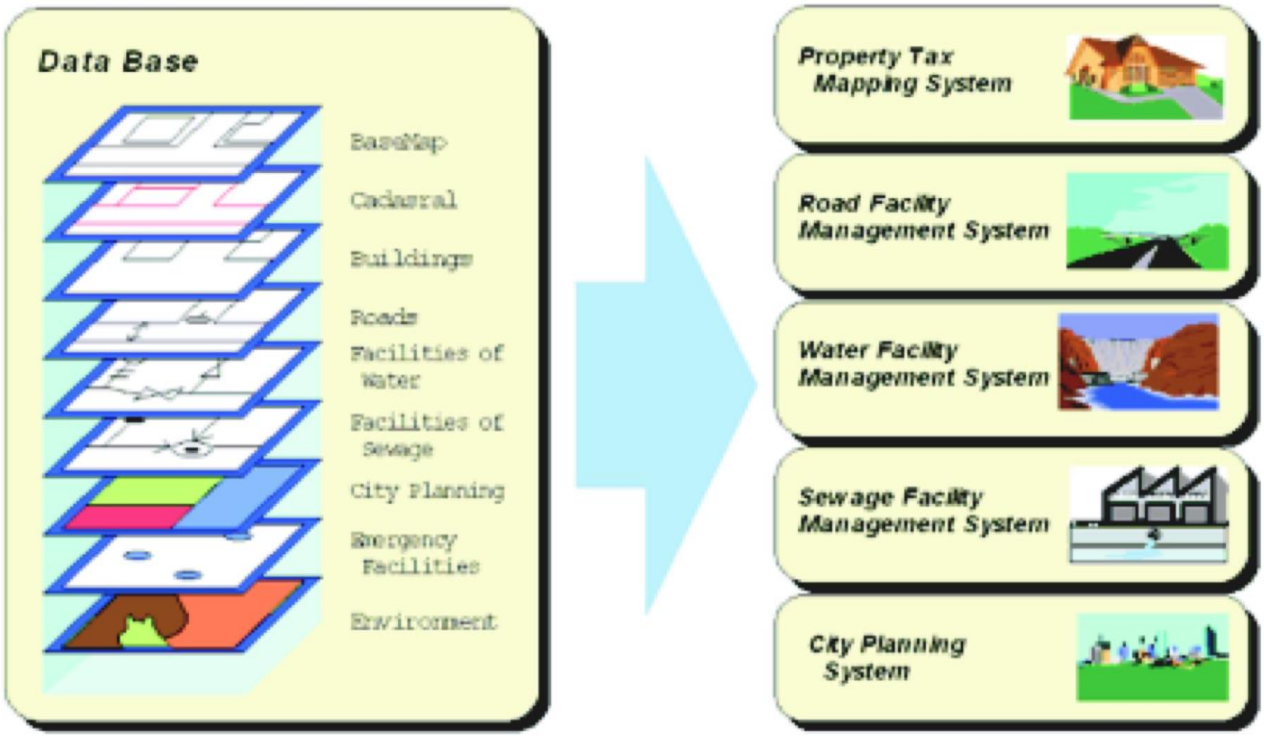


Fig. 6: Applications of Enterprise GIS

GIS Customisation and Software Automation: With the advent of web applications/client server concept, several organisation are opting for software customisation to make it more user friendly for their clients/customers. Client/customer would be more happy to get the results or output at the click of the button rather than

bother about the long and tedious back end process. In the current scenario, GIS customisation has got numerous benefits as mentioned below:

• it reduces the cycle time of certain project processes

• manual intervention could be greatly minimised

• human induced errors are significantly reduced as the process is automated

• with little modification of the custom built application, the same tool or scripts could be reused in other applications as well.

Most of the customisation is being carried out to create Spatial Decision Support Systems (SDSS), which use inherent capabilities of GIS and provides better analytic capabilities and visualisation in the form of tailor-made maps. This facilitates decision making to a great extent (Fig. 7). In a typical SDSS for forest management, the vision/need comes from the forestry experts, which ultimately gets transformed into a database. The efficient use of this dataset through GIS and IT can be extremely helpful in deriving the most meaningful information necessary for better governance. Another important benefit of SDSS is that it can even be used by the people who do not have any specific background related to GIS and IT. SDSS named 'Aranya has been developed by Centre for Development of Advanced Computing (C-DAC) for forest department, 'Bodoland Territorial Areas District (BTAD), Assam, under the Government of India initiative for promoting IT-based services in Northeast India. Aranya has been developed using open source tools including Quantum GIS (QGIS), Python, PyQt, C and C++ to ensure its wider dissemination.

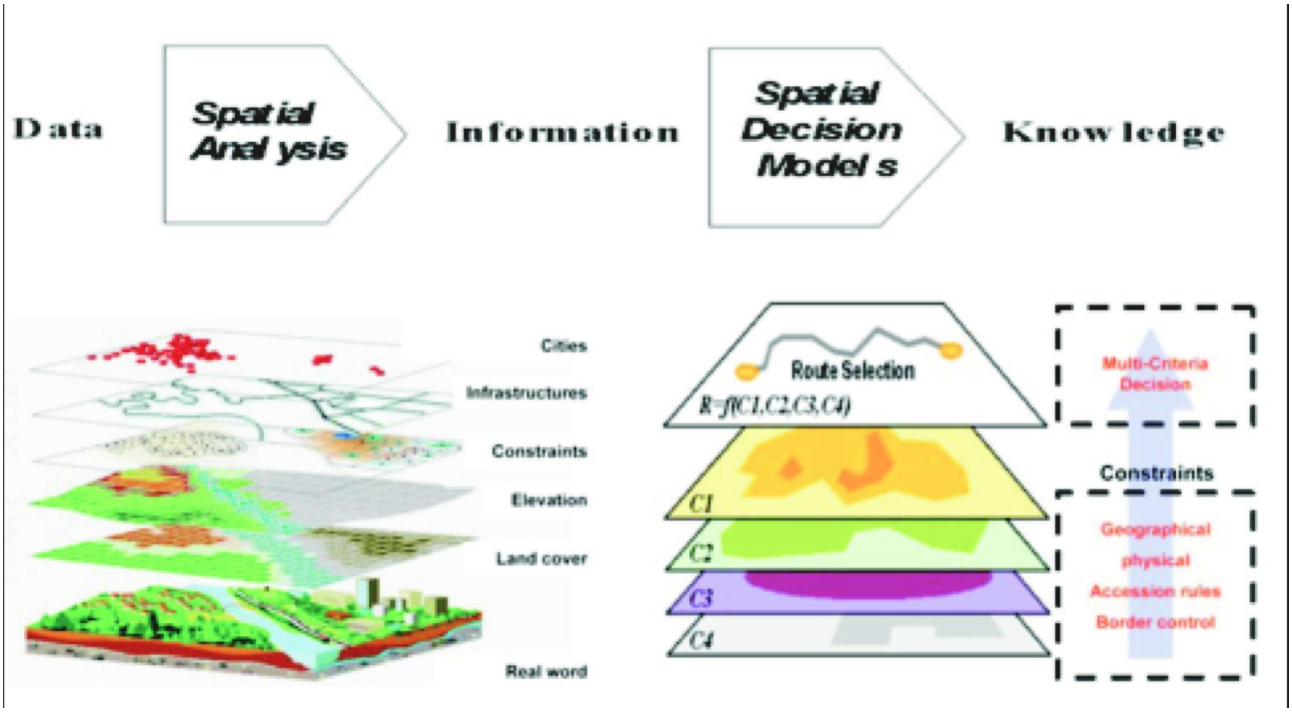


Fig. 7: Illustration showing function of SDSS

QGIS is a GIS package having compatibility with GRASS (a comprehensive open source image processing and GIS software) and can be customised using Python language. Python is an easy to use and robust scripting language, and can be integrated with C, C++, Fortran and Java. Further, QGIS works in plug- in mode which provides the

flexibility to invoke or revoke a particular module. Plug-ins are programs (dynamically linked libraries) responsible to carry out specific tasks, and can be called in QGIS in runtime environment; even different modules of GRASS can be called as plug-ins. Further, Python can effectively be used with both grid (raster) and vector formats. PyQT is a Python binding for Nokia′s QT application framework and runs on the windows.

Aranya is aimed at providing the flexibility to forest managers and planners to do various analyses in GIS. It has different modules relevant to forest departments in India. These include territorial forestry, joint forest management, and wildlife, working plan and research and development.

GIS Technology Advancements in the Last 5 Years: Government agencies, nonprofit organizations and private companies all benefit from innovations in Geographic Information Science (GIS). Researchers and entrepreneurs have found a variety of creative ways to use GIS to advance business and technology. The latest GIS technology developments make way for new applications and for the convergence of GIS with other emerging tools.

The evolution of GIS is far from over, with exciting new software and methods continuing to change the way people utilize this technology. Let′s take a look at three of the most promising recent trends in GIS:

Real-Time Data: The ability to collect and analyze data in real time brought GIS to a whole new level. This development improved research processes and mapping systems, but real-time geospatial data can benefit consumers, too.

Location-based services like Uber are among the most common uses for up-to-the-minute geographic information. Consumers can track where their drivers are and how long it′ll take them to arrive. The app also employs real-time data to match users with the closest ride and directs drivers to hot spots based on the frequency of ride requests.

Real-time geospatial intelligence can also be an effective way to track developments during natural disasters. Analysis of everything from shifting weather patterns to social media posts highlight locations in urgent need of relief efforts. Emergency management services use GIS platforms to generate crisis maps based on a combination of:

- Satellite imagery
- Remote sensor readings
- Statistical models
- Crowdsourced data

When facing time-sensitive decisions, it′s important to have the most relevant and accurate data. Robust geographic information is a boon to organizations and individuals striving to make well-informed decisions, and ongoing refinements to real-time data analysis are vital to the future of GIS.

Consumer-Facing Information: Geospatial data has helped companies in a wide range of industries streamline their operations by providing greater visibility into key assets and guiding more efficient supply chains. But everyday consumers can also take advantage of

current trends in GIS. Some of the latest GIS technology has brought consumer-facing data to the forefront, empowering smart decisions in many areas.

Consider homebuying: A house might be in your price range, but the neighborhood can make all the difference in whether it′s the right choice for your family. That′s why real estate apps now use GIS platforms to give prospective homebuyers insights into the areas they′re considering. Dozens of map layers let users review details like distance to various amenities, school district information and more. People aren′t just looking at photos on home search websites anymore; they′re scouring details about what it feels like to live in an area.

The health and wellness industry underwent a major shift in recent years with many consumers applying data to manage their own lifestyles. Wearable technology lets individuals track their heartrate, steps, sleep patterns and the paths they follow when running or walking. With geospatial information, personal fitness goals become more attainable, and these advances have even made a mark in college and professional sports: Coaches can factor the personal data from players GPS-enabled wearables into their strategic decisions, snagging victory while minimizing the chance for injury.

Artificial Intelligence: Artificial intelligence is another rapidly evolving technology that has been applied to GIS projects in recent years. One important application for GeoAI is in planning urban infrastructure and tracking changes in an area over time.

For example, researchers in Los Angeles wanted to know how land use and roadways impacted air pollution and, in turn, how pollution would affect health in local residents. GIS helped them analyze traffic patterns over different times of day in relation to the concentration of harmful particles in the air. By using this information to predict when pollution levels would become dangerous, the city could issue warnings as early as possible.

In another project that utilized GeoAI, Kuwaiti government officials wanted to make it easier for citizens to find products and services they needed by using an application. Like many big cities, traffic congestion was a major obstacle, and the government wanted to be able to tell users what road conditions were like at any given time. The application gave users the ability to share whether they were seeing heavy, moderate or light traffic, which helped the researchers identify traffic patterns. When there was heavy traffic on one route, the application would deliver directions to avoid traffic jams.

The application initially relied on user input and manual updates to identify traffic, requiring constant adjustments to the machine learning algorithm. With the introduction of GeoAI, the application gained a deeper understanding of traffic conditions and greater predictive capabilities, which in turn led more useful driving instructions.

GeoAI is still evolving and has the potential to be one of the future trends in GIS that makes the biggest impact on daily life. In addition to land use and infrastructure analysis, GeoAI can also be applied to health systems, agriculture and many more industries.

The GIS AR Opportunity: GIS of the future may very well be in augmented reality and virtual reality. AR and VR use continues to grow as users become more comfortable with the technology, and this will lead to more and more developers integrating GIS capabilities into their applications, Benton said. These GIS-enabled AR apps could be used by anyone from architects to oil workers and municipal services to see location and

orientation of objects underground. And game developers in the future will likely be using GIS to create virtual worlds to serve as the creative mind′s playground.

This is one of the areas where 3D and mobile GIS are likely to converge. Powered by 3D spatial information, mobile GIS applications will be able to create immersive experiences anywhere out in the field. Early examples of this trend can be seen in popular games like Pokémon Go but the potential for immersive AR visualizations is limitless.

Indoor Mapping, UI, AND IOT: In the same way that GIS is used to make maps of cities and roadways, the technology is now being used to develop indoor maps. While it′s still in the early stages of development and adoption, future trends in GIS have indoor mapping likely to skyrocket in popularity in the coming years as people have more of a need to navigate large, complex buildings. For example, more sophisticated and detailed indoor mapping technology may drastically improve safety for emergency responders, who would have improved access to layout, points of entry and other critical information when arriving at the scene of an incident.

One of the biggest changes for developers in the future of GIS will come at the user interface (UI) level, Benton said. ″These interfaces will make developing work a lot easier because it will feature an easy-to-understand environment that intuitively helps the user to create, add, edit, and remove elements,″ she wrote. She later added, ″An introduction of the user interface is a major breakthrough because it will make the maps friendlier to developers as well as everyone who uses them.″

As Dangermond said, ″[M]aps are the visual language for understanding the context of data.″ Dangermond believes that the next major leap in the future of GIS will be tapping in to the growing network of Internet-connected devices that make up the Internet of Things. By leveraging all the connected devices, GIS practitioners will be able to get even more data in real-time.

Geographical tracking and mapping of coronavirus disease COVID-19/severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) epidemic and associated events around the world: How 21st century GIS technologies are supporting the global fight against outbreaks and epidemics:

Introduction: In December 2019, a new virus (initially called ′Novel Coronavirus 2019-nCoV and later renamed to SARS- CoV-2) causing severe acute respiratory syndrome (coronavirus disease COVID-19) emerged in Wuhan, Hubei Province, China, and rapidly spread to other parts of China and other countries around the world, despite China′s massive efforts to contain the disease within Hubei. Compared to the 2002/2003 SARS-CoV and the 2012–2014 MERS-CoV (Middle East Respiratory Syndrome-related coronavirus), the COVID-19 coronavirus spread strikingly fast. While MERS took about two and a half years to infect 1000 people, and SARS took roughly 4 months, the novel SARS-CoV-2 reached that figure in just 48 days. On 30 January 2020, the World Health Organization (WHO) declared that the new SARS-CoV-2 coronavirus outbreak constitutes a Public Health Emergency of International Concern (PHEIC).

As with the original SARS-CoV epidemic of 2002/2003 and with seasonal influenza, geographic information systems (GIS) and methods, including, among other application possibilities, online real- or near-real- time mapping of disease cases and of social media reactions to disease spread, predictive risk mapping using population travel data, and tracing and mapping super- spreader trajectories and contacts across space and time (see,

as an example, the first diagram in), are proving indispensable for our timely understanding of the new disease source, dynamics and epidemiology, and in shaping our effective response to it.

Indeed, health professionals have long considered conventional mapping, and more recently geographic information systems (GIS), as critical tools in tracking and combating contagion. The earliest map visualisation of the relationship between place and health was in 1694 on plague containment in Italy. The value of maps as a communication tool blossomed over the next 225 years in the service of understanding and tracking infectious diseases, such as yellow fever, cholera and the 1918 influenza pandemic. From the 1960s, when computerised geographic information systems were born, the possibilities for analysing, visualising and detecting patterns of disease dramatically increased again. A 2014 review of the health GIS literature found that 248 out of 865 included papers (28.7%) focused on infectious disease mapping.

Since then we have seen a revolution in applied health geography through Web-based tools. Now, as we deploy these tools to protect human lives, we can ingest big data from their sources and display results in inter- active and near-real-time dashboards. These online dashboards have become a pivotal source of information during the COVID-19 outbreak.

This paper offers pointers to, and describes, a range of practical online/mobile GIS and mapping dashboards and applications for tracking the coronavirus epidemic and associated events as they unfold around the world. Some of these dashboards and applications are receiving data updates in near-real-time (at the time of writing), and one of them is meant for individual users (in China) to check if the app user has had any close contact with a person confirmed or suspected to have been infected with SARS-CoV-2 in the recent past. We also briefly discuss additional ways GIS can support the fight against infectious disease outbreaks and epidemics.

Johns Hopkins University Center for Systems Science and Engineering dashboard: When disease can travel so quickly, information has to move even faster. This is where map-based dashboards become crucial. At the time of this writing in mid- February 2020, seven coronavirus dashboards are among the top ten requested applications from Esri ArcGIS Online service, accumulating over 160 million views. First published on 22 January 2020 in response to escalating pandemic fears in late January 2020, the Johns Hopkins University′s Center for Systems Science and Engineering (JHU CSSE) dashboard leads the pack, garnering 140 million views. Developed by Lauren Gardner (an epidemiologist) and her team from the JHU CSSE, the dashboard went viral with hundreds of news articles and shares on social media (Fig. 1). This intense response to the JHU CSSE and other dashboards shows how eager people are to track health threats. Anyone with Inter- net access can learn, in a few short clicks, a tremendous amount of information about the COVID-19 virus from these resources.

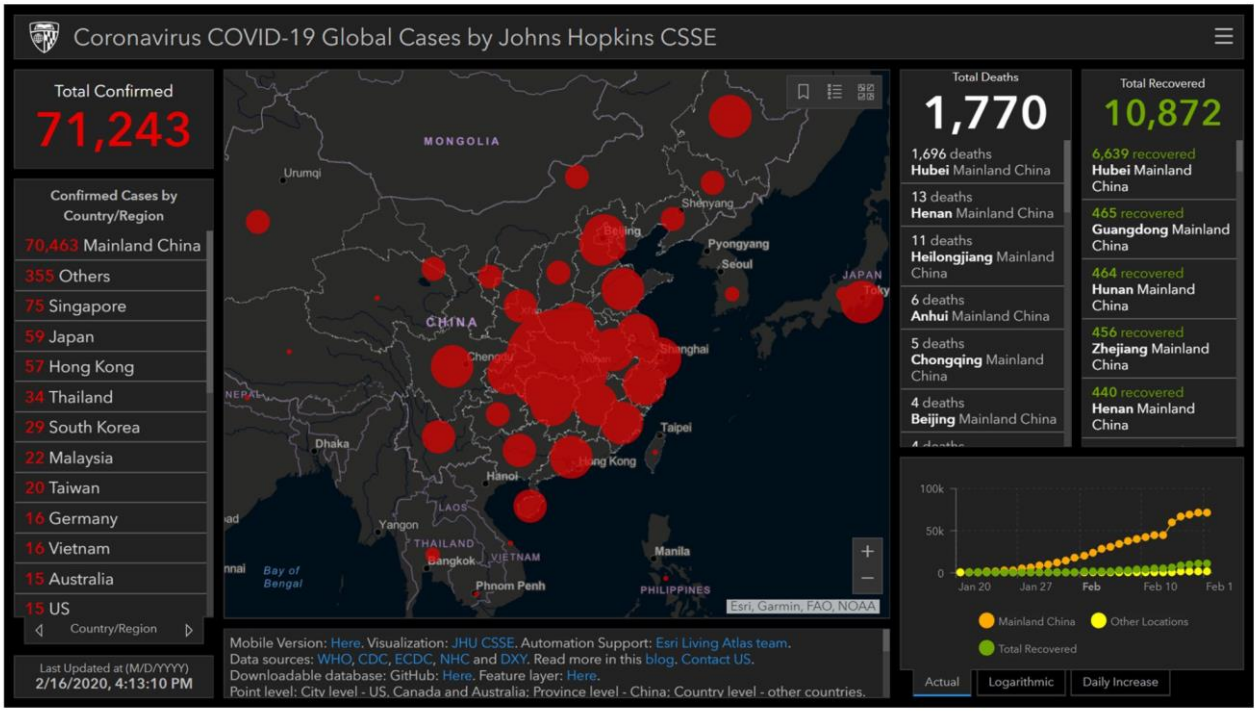


Fig. 1 Johns Hopkins University CSSE is tracking the spread of SARS-CoV-2 in near real time with a map-centric dashboard (using ArcGIS Online) that pulls relevant data from the WHO, US CDC (Centers for Disease Control and Prevention), ECDC (European Centre for Disease Prevention and Control), Chinese Center for Disease Control and Prevention (CCDC), NHC (China's National Health Commission), and Dingxiangyuan (DXY, China). Screenshot date: 16 February 2020

The JHU CSSE dashboard′s interactive map locates and tallies confirmed infections, fatalities and recoveries. Graphs detail virus progress over time. Viewers can see the day and time of the most recent data update and data sources. The dashboard′s five authoritative data sources include World Health Organization (WHO), US Centers for Disease Control and Prevention, National Health Commission of the People′s Republic of China, European Centre for Disease Prevention and Control, and the Chinese online medical resource DXY.cn. The dashboard provides links to these sources and others. A blog post details this work. The corresponding data repository is accessible as Google sheets in GitHub.

Web services allow GIS users to consume and display disparate data inputs without central hosting or processing to ease data sharing and speed information aggregation. In the first dashboard iteration, from January 22 through January 31, 2020, the Hopkins team manually updated data twice per day. In February 2020, Esri′s ArcGIS Living Atlas team assisted them in adopting a semi-automated living data stream strategy to update the dashboard. It primarily relies on the DXY.cn data resource, which updates every 15 min for case reports at provincial and country levels. However, Lauren Gardner′s blog notes that for countries outside of China, other data resources were quicker to update than DXY. cn, so those case counts are manually updated through- out the day. Current feature layers are freely accessible in the ArcGIS Living Atlas.

Yet, the COVID-19 outbreak has been difficult to monitor. As Gardner explains, ″it is especially challenging to collect good data at a fine spatial resolution, which is what most

people want to know, and without having travel data in real time that captures these altered mobility patterns, it is hard to assess what the geographic risk profile will look like moving forward".

The JHU CSSE dashboard (at the time of writing) lacks archiving services for full retrospective map visualisation of data from previous days. As far as the latter are concerned, the dashboard only offers timeline charts of total confirmed cases (grouped into 'mainland China and 'other locations') and total recovered cases. But one is unable to retrieve and display detailed map snapshots in time (by individual country/region and Chinese province), e.g., to see how the coronavirus world distribution map looked in the past on a specific day, such as 25 January 2020. The dashboard developers are encouraged to compile and make such interactive daily map snapshots permanently accessible online for future reference after the epidemic has gone, as a service to public health researchers and professionals worldwide.

The World Health Organization dashboard: The WHO directs and coordinates international health, combating communicable diseases through surveillance, preparedness and response, and applying GIS technology to this work. On 26 January 2020, the WHO unveiled its ArcGIS Operations Dashboard for COVID-19, which also maps and lists coronavirus cases and total number of deaths by country and Chinese province, with informational panels about the map and its data resources (Fig. 2).

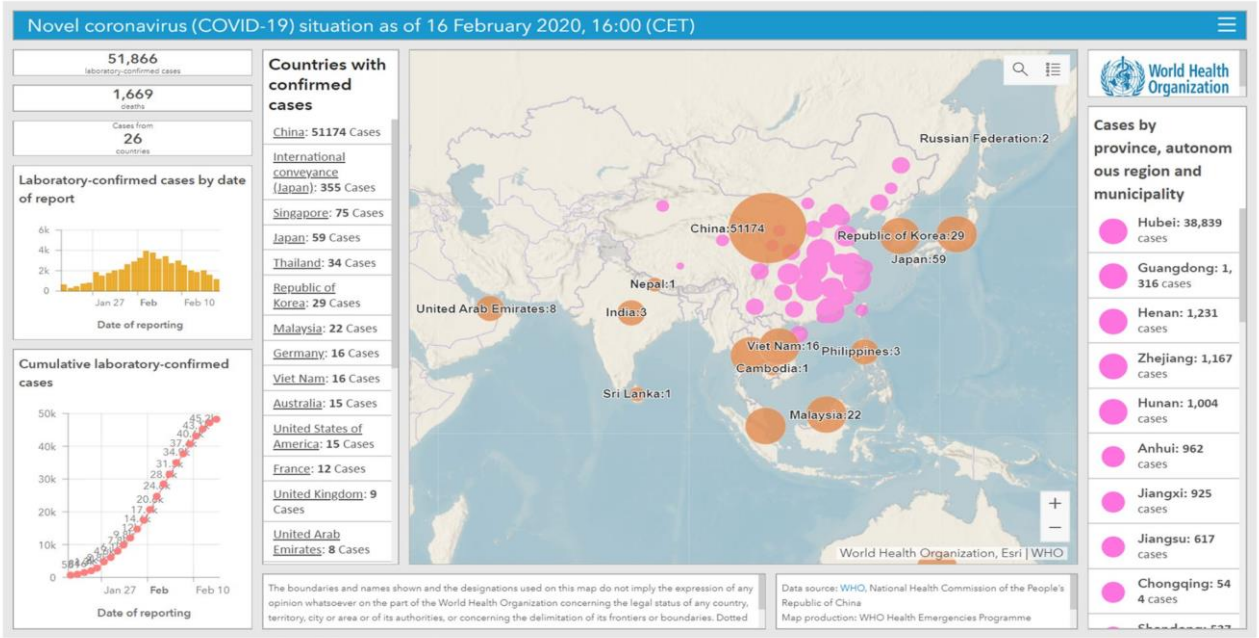


Fig. 2 The WHO COVID-19 situation dashboard. Screenshot date: 16 February 2020

Prior to 18 February 2020, the WHO and JHU CSSE dashboards had some interesting differences. Each had a vastly different total case count as can be seen in Figs. 1 and 2 (both taken on 16 February 2020). The WHO dashboard reflected laboratory-confirmed cases, whereas JHU CSSE included cases diagnosed using a symptom array plus chest imaging (accounting for some 18,000 additional reports). However, as of 19 February 2020, both dashboards are in sync, displaying similar total case counts.

The WHO dashboard includes an epidemic curve up front, showing cases by date of reporting. Putting the epi curve visualisation above the cumulative cases graph provides important information about outbreak progression, and may decrease fear since we can see a steady decline in the total number of new cases per day since 4 February 2020 (except for a spike on 13 February 2020, when more than 15 K cases were added after China started to include ′clinically diagnosed cases and not just laboratory-con- firmed cases in its figures).

A ′hamburger menu at the top right corner of the WHO dashboard provides links to additional information about COVID-19 and leads to an interactive Web map that puts COVID-19 into context among other WHO-monitored health emergencies, such as dengue fever, Rift Valley fever and West Nile fever.

The WHO is updating its COVID-19 dashboard automatically using ArcGIS GeoEvent Server to push updates to a single feature service multiple times per day. The WHO dashboard optimisation measures include moving tiled data off its server and into ArcGIS Online tiled services to benefit from Esri′s content delivery network. This allows good map performance at 10–12 levels of zoom.

Both the WHO and JHU CSSE dashboards consider the importance of mobile devices. Among dashboards built with Esri′s ArcGIS Operations Dashboard app, nearly 8% of viewers choose those built for mobile consumption. Consistent with how people want to receive information, mobile-optimised dashboards are versatile and accessible on phones or tablets.

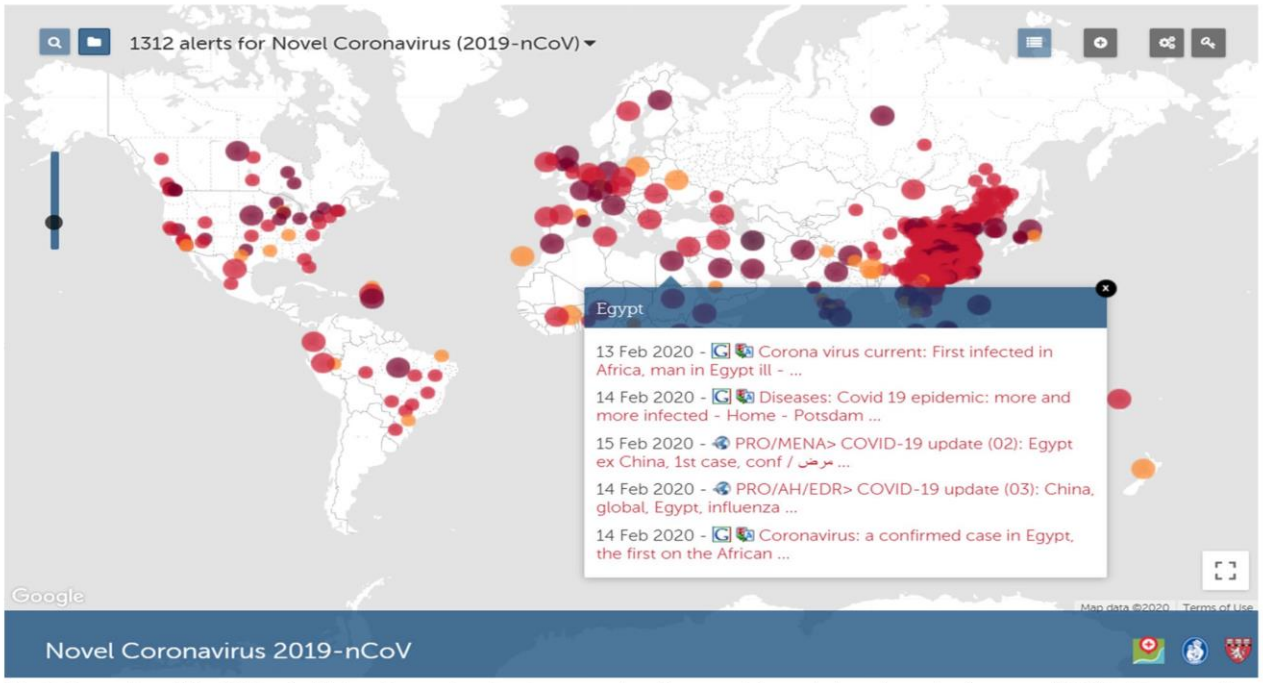


Fig. 3 Screenshot of HealthMap for Wuhan Coronavirus showing a number of news articles and alerts about the first case of COVID-19 reported in Africa (Egypt) on 13 February 2020. Screenshot date: 17 February 2020. (HealthMap uses base map data from Google.)

HealthMap: analysing and mapping online informal sources: Founded in 2006, HealthMap is run by a team of researchers, epidemiologists and software developers at

Boston Children′s Hospital, USA, and uses online media sources for real-time surveillance of emerging public health threats. HealthMap collates outbreak data from a range of sources, including news media (e.g., via Google News), social media, validated official alerts (e.g., from the WHO) and expert-curated accounts. Health- Map′s interactive map for SARS-CoV-2 available at offers near-real-time geolocated updates from these sources to better understand the progression of the pandemic (Fig. 3).

In the same vein as HealthMap, BlueDot, a Canadian firm specialising in automated infectious disease surveil- lance, uses machine learning and natural language processing techniques to sift through news reports in 65 languages, forum and blog posts, airline ticketing data, animal disease networks, etc., to pick up indications and news of unusual, unfolding events and possible disease outbreaks. The firm employs trained epidemiologists to further analyse outbreak results obtained by automated means before releasing them to its clients, and is said to have been among the earliest to break news of COVID- 19 outbreak as it started in China.

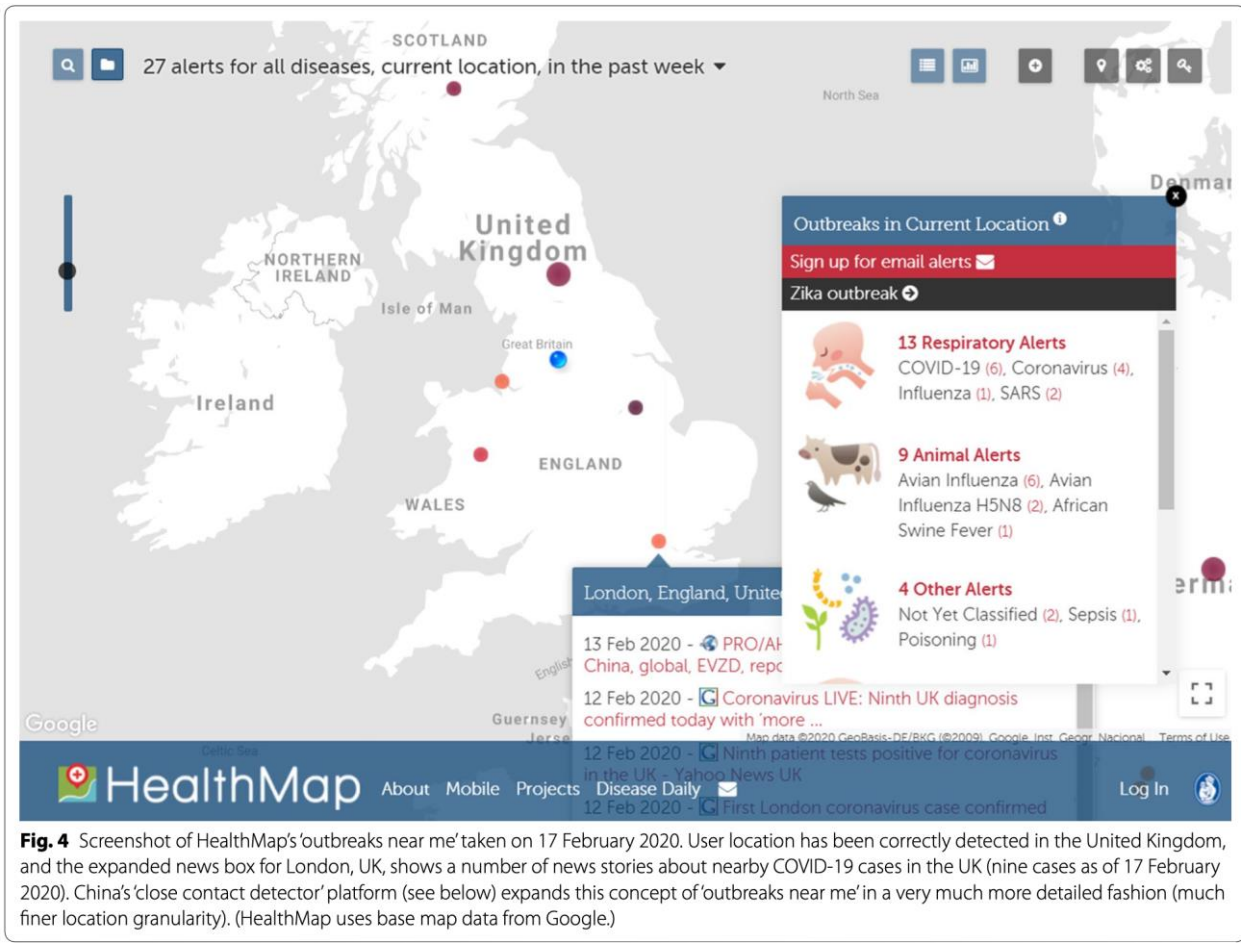


Fig. 4 Screenshot of HealthMap's 'outbreaks near me' taken on 17 February 2020. User location has been correctly detected in the United Kingdom, and the expanded news box for London, UK, shows a number of news stories about nearby COVID-19 cases in the UK (nine cases as of 17 February 2020). China's 'close contact detector' platform (see below) expands this concept of 'outbreaks near me' in a very much more detailed fashion (much finer location granularity). (HealthMap uses base map data from Google.)

HealthMap also offers an ′outbreaks near me feature that informs individual users about nearby disease transmission risks based on their current location as obtained from their Web browser/smartphone (Fig. 4).

China′s coronavirus ′close contact detector geosocial app and public service platform:

While government travel restrictions initiate social distancing, it is now possible for individuals to further the cause by using a dedicated app that provides a detailed spatial scale to support informed personal decisions about self-quarantine and seeking medical treatment. Co-launched by China′s National Health Commission and China Electronics Technology Group Corporation, the ′close contact detector app/platform uses big data from public authorities about the movement of people (public transport data covering flights and trains [booking a train seat in China requires the input of ID information]), as well as disease case records, to check if the user has had any close contact with a person confirmed or suspected to have been infected in the recent past (Fig. 5). The platform can inform the user based on her/ his location and recent movements whether s/he has within the last 2 weeks (the assumed incubation period of COVID-19) worked together, shared a classroom, lived in the same building, or travelled by train (all passengers and crew members in the same carriage) or plane (cabin staff and passengers within three rows of an infected person) with a person confirmed or suspected to have the virus. ′Close contact detector can be accessed via three of the most popular mobile social and payment apps in China, namely Alipay, WeChat and QQ.

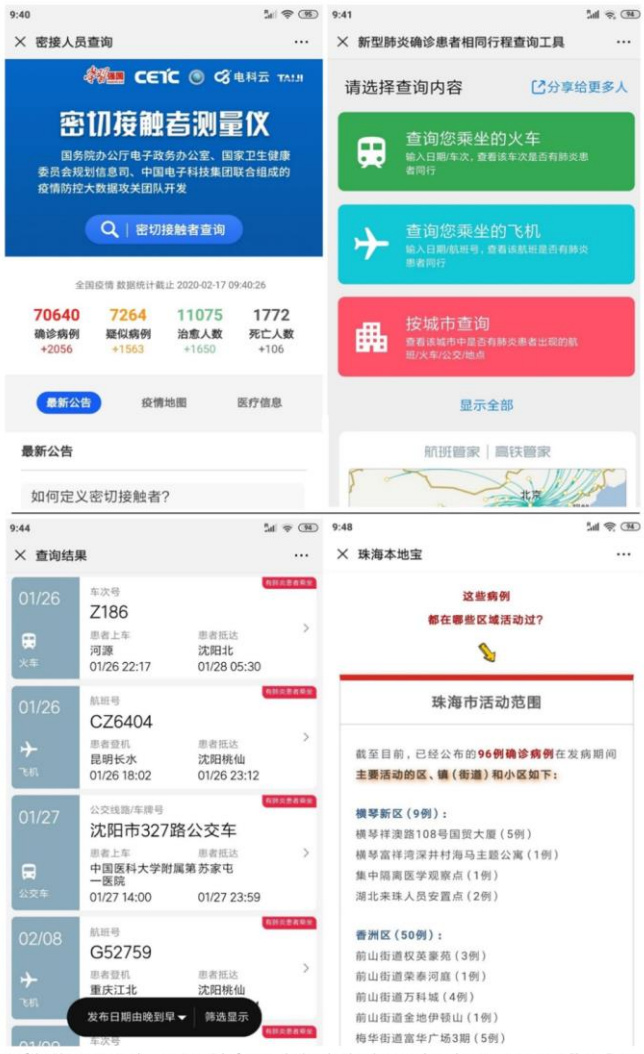


Fig. 5 Screenshots of the′close contact detector′app/platform and related online location-based inquiry services in China. Functions include close contact inquiry, including train journey number and plane flight number checking for diagnosed cases, and location information about the activity spaces of nearby confirmed cases (no individual names are ever displayed in returned results). These screenshots were taken on 17 February 2020

The platform might raise some location data privacy questions among some audiences, even though it explicitly asks its users to observe China′s cybersecurity laws and not abuse private information, and has been very well received by the public in China. As explained by Carolyn Bigg, a Hong Kong-based technology lawyer at the law firm DLA Piper, in a comment to the BBC, ″In China, and across Asia, (individual) data are not seen as something to be locked down, but as something that can be used, provided this is done in a transparent way, with consent where needed. From a Chinese perspective this is a really useful service for people and a really powerful tool that shows the power of data being used for good".

A related and complementary voluntary system was implemented in Guangzhou Underground (Guangdong Province, China), so that if a person is later diagnosed with coronavirus, it would be easier to track her/ his transport routines and notify related passengers who boarded the same metro carriages. Starting on 17 February 2020, every metro carriage in Guangzhou Underground displays a unique QR code that passengers are invited to scan once they board the carriage. They then need to quickly fill in an online form that appears on their phone, which includes name, ID No. (optional), gender, their starting metro station and their destination station. As each carriage has a unique QR code, if the passenger walks into another carriage during transportation, s/he will have to scan the new QR code of that carriage and (auto) fill in the corresponding form again. If the passenger′s journey involves changing to other metro lines to reach their final destination, then s/he will have to repeat the same process for every additional carriage they board (Fig. 6).



Fig. 6 The Guangzhou Underground COVID-19 tracking and notification service. The actual practical value and ultimate success of such services deployed for the first time should be documented and confirmed at the end of the outbreak, so that the world community can learn from the experience

WorldPop and EpiRisk predictive global risk analytics and maps for SARS-CoV-2 based on population movements out of Wuhan and travel destinations:

Human mobility places scientists at a serious disadvantage in slowing potential epidemics. A person can pick up a virus in one place and share it to another location within hours. Among the jet set, there is potential to become a super spreader, infecting many people across an expansive geographical area. While vaccine technology has advanced significantly, it still takes a year or more to formulate a vaccine—time enough for the virus to reach every corner of the world.

The last trains and scheduled domestic and international flights left Wuhan the morning of 23 January 2020, putting an end to a surge of outbound Chinese Lunar New Year travel that had started 3 days earlier (Fig. 7). The WHO commended the move by Chinese authorities to place Wuhan under quarantine, which was unprecedented at scale. By the end of January 2020, Chinese authorities had enforced further transportation restrictions in 15 additional cities.

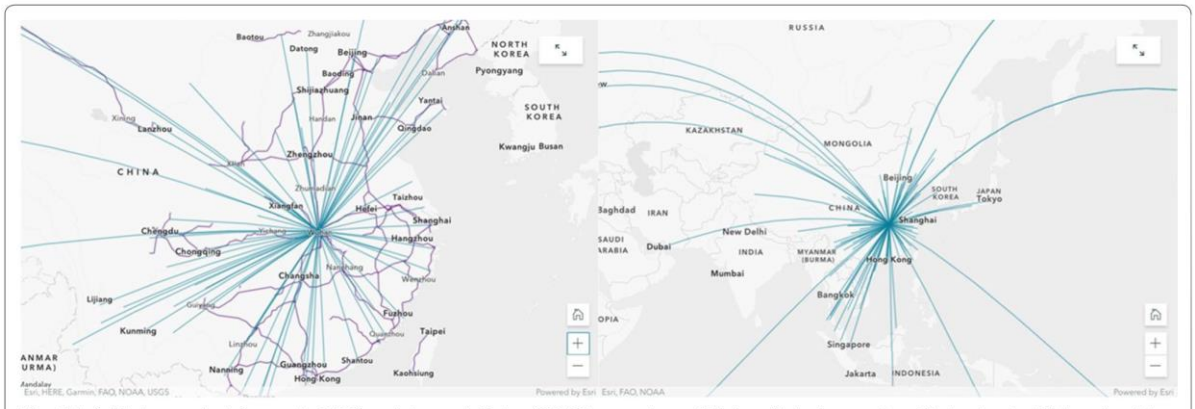


Fig. 7 Left: High-speed rail (in purple; 2016) and domestic flights (2018) into and out of Wuhan. Right: International flights leaving Wuhan (partial map; 2018). Wuhan, a major regional transit hub, connects directly to dozens of cities in China. Despite strong actions to curb the spread, an estimated five million people potentially exposed to the virus had already left Wuhan before the city was placed under quarantine, complicating containment efforts. Understanding travel patterns can help health authorities worldwide establish quarantine stations and passenger screening programmes at major international airports

The WorldPop research group at Southampton University, UK, used historical data and patterns from Baidu′s location services and international flight itineraries to better understand population movements out of Wuhan prior to the city′s lockdown, look at travellers volumes and destinations across China and the world, and compile a predictive global risk map for the likely spread of SARS-CoV-2 virus from its epicentre in Wuhan. According to WorldPop′s analysis, within mainland China, the cities of Beijing, Guangzhou, Shanghai and Chongqing are all identified as high-risk, while the most ′at-risk places worldwide are Thailand (1st), Japan (2nd) and Hong Kong (3rd), followed by the USA (6th), Australia (10th) and the UK (17th).

It is noteworthy that WorldPop also mapped population distributions and mobility patterns (mobile phone flow maps using mobile telecom data) in West African countries to support efforts in controlling the 2014 Ebola virus outbreak. Spatial analysis methods are indeed powerful for modelling disease spread, detecting patterns and statistically significant hotspots, and predicting what will happen next.

Similar work has been conducted at Northeastern University, Boston, Massachusetts, USA, to develop predictive models of the COVID-19 epidemic using EpiRisk, a tool that estimates the probability that infected individuals will spread the disease to other parts of the world via air travel. Epirisk also tracks the effectiveness of travel bans and is part of the GLEAM (global epidemic and mobility model) project.

Mapping the worldwide spread of misinformation about coronavirus: During infectious disease outbreaks and epidemics, social media play an important role in communicating verified facts and correct prevention tips to the masses, but also carry the risk of ′virally spreading misinformation, confusion and fear among the general public. In the case of COVID-19, false or misleading information, (such as ′eating sesame oil or garlic can help prevent and cure coronavirus and a decade-old map showing global air travel), rumours and panic have been spreading globally on social media much faster than the virus.

To partially illustrate this phenomenon, Twitter user Mehdi Moussaïd (@Mehdi_Moussaid), a research scientist at Max Planck Institute for Human Development, Berlin, Germany, published an animated map of the world on his account showing the worldwide propagation of the hashtag#coronavirus on Twitter (in green) and the actual cases of coronavirus (in red) between 24 and 31 January 2020 (Fig. 8). Of course, not all tweets and retweets with the hashtag #coronavirus are spreading misinformation, and many of them originate from legitimate bodies and organisations such as the WHO, but the map serves as a good illustration of the ′viral nature of Twitter and other social media. A more detailed map set covering other coronavirus hashtags and classifying tweets by their truthfulness before mapping them could offer valuable insights and guidance for social media companies and health organisations worldwide in their fight against misinformation.



Fig. 8 Screenshot of the tweet by @Mehdi_Moussaid on 3 February 2020 featuring an animated map of the worldwide propagation of the hashtag #coronavirus on Twitter (in green) and the actual cases of coronavirus (in red) between 24 and 31 January 2020

In fact, it has been said that the WHO is fighting a parallel pandemic (or ʹinfodemicʹ) of misinformation besides COVID-19. The WHO has joined forces with social media giants such as Facebook, Twitter, You- Tube (Google) and Pinterest to combat the spread of misinformation around coronavirus. For example, Pinterest and YouTube users can now (at the time of writing this article) see a link prominently displayed that points to an official WHO page about COVID-19 whenever they search for, or browse/watch, material about coronavirus on these platforms.

Other ways GIS technologies can help in combat infectious disease outbreaks and epidemics:

During the COVID-19 outbreak, map-centric dash- boards, such as the ones by Johns Hopkins CSSE, the WHO and Early Alert Inc., have gone viral themselves, informing both the public and health professionals. But dashboards are just the beginning of how

GIS and location technologies can support the fight against infectious diseases. Following are a few more examples.

Outbreak source: John Snow (1813–1858) was able to trace the source of a cholera outbreak in Soho, London, in 1854, thanks to his well-known manual spatial analysis exercise using handdrawn paper maps of cholera cases and water pumps/ water companies supplying them with water. Today, more advanced computerised spatial analyses integrating phyloepidemiological methods are used to identify the likely sources of new outbreaks;

Public events: An important factor affecting epidemics such as COVID- 19 is the calendar. During the Ebola and MERS scares of 2014, many people considered cancelling their participation in the Hajj pilgrimage to Mecca made by over two million Muslims every year. Equipped with days-old data and rumours, many faithful proceeded with their pilgrimage, putting themselves at risk of contracting potentially deadly viruses and further spreading disease when they returned home.

In the coronavirus outbreak, Chinese New Year celebrations posed a threat as the themes of togetherness and reunion trigger the largest human migration in the world. The Chinese government extended the Lunar New Year holiday to reduce mass gatherings (that were to happen upon return to work and schools), a public health intervention called social distancing. Travellers worldwide were subsequently restricted from entering China. With access to current information, authorities in Beijing, Macao and Hong Kong cancelled many major festivities.

Dashboards and Web maps that bring together location and time-sensitive events in relationship to a spreading disease give travellers and officials the potential to reduce exposure.

Site selection: Facing treatment facility shortages in Wuhan, government officials commissioned in late January the emergency construction of two new hospitals, which together provide an additional 2600 beds. Construction teams finished the first hospital on 2 February 2020, just 10 days after breaking ground. The second facility received its first patients on 6 February 2020. Site selection, whether for emergency treatment units or permanent infrastructure, is a common and high-value application of GIS technology.

Supply chain: During public health emergencies of international concern, we often see shortages of medicines and supplies. Shortages can have significant consequences such as hoarding and price gauging by suppliers or distributors. Sometimes, the impacted places are also manufacturing centres for the supplies, leading to a production decline. Digital supply chain maps prove foundational to planning and ensuring geographical diversity in suppliers as well as aligning needs with distribution.

Resource locators: Residents of affected areas can use publicly available applications to locate crucial aid and resources. Apps and maps can display information and navigation to hospitals with available beds, clinics offering medical aid along with current wait times, grocery stores and pharmacies that are open, places to purchase personal protective equipment, and more. In heavily impacted cities, this information could critically improve outcomes and save lives.

Drones: In China, unmanned aerial vehicles (UAV) are transport- ing crucial medical supplies and patient lab samples. In highly impacted areas, drones reduce human contact with lab samples and free up ground transport assets and personnel. Drones are also being

used for broad disinfectant operations in China. Integrated drone and GIS technologies can help target and speed efforts in places they are needed most.

Conclusions : Modern GIS technologies centre around web-based tools, improved data sharing and real-time information to support critical decision-making. Dashboards exemplify those ideals and have been extremely popular in sharing and understanding the spread of SARS-CoV-2 coronavirus. Communication through map-based dash- boards offers accessible information to people around the world eager to protect themselves and their communities. This tool type improves data transparency and helps authorities disseminate information.

Certainly, dashboards have taken centre stage in COVID-19 outbreak awareness. But we hope that readers consider how a comprehensive GIS platform can support the entire process of infectious disease surveillance, preparedness and response, because as one epidemiologist put it, outbreaks like this ″should be expected to happen more frequently moving forward". In other words, it is not a question of if another outbreak will occur, but when and where. Viruses like SARS-CoV-2 know no country or continent boundaries.

Multi-source 3D and AI analytics: Intel has launched a Cloud geovisual data management platform in partnership with 14 other geospatial and IT companies. The platform, called Intel Geospatial, features multi-source 3D data and AI-powered analytics to help transform the way industries manage their assets, including Utilities, Smart cities, and Oil and Gas.

IT majors such as AWS and SAP, and geospatial companies such Hexagon, Bentley, Cesium, Woolpert, Enview, Pix4D, among others are part of the initiative. The platform brings together multi-source data types — from satellites to manned aircraft to drones as well as terrestrial sensors like those in vehicles — to provide customers geovisual data management, immersive 3D visualization, analytic applications, and enterprise integration.

″Intel Geospatial is turning labor-intensive asset management into a streamlined, data-driven science, making it easy to extract business insights at scale," Intel said in statement on Tuesday. Additionally, there is support for LiDAR and other sensors, across satellite, aerial and terrestrial capture methods.

What is Intel Geospatial: The advanced tiling enables fast and easy navigation on a global scale with enhance 3D visualization, enabling third party developers with the tools they need to transform geospatial data into smarter, more efficient business solutions. The platform seeks to address key business challenges such as geovisual data management — managing multi-source geovisual data in a centralized system; asset record correlation — reconciling records and geolocate assets in the field; vegetation management — automate vegetation encroachment baseline and analyze right of way; and fire risk assessment — visually inspect assets, analyze fire break clearance, and more.

″We are excited to partner with Intel to provide optimal resources for our clients and to help define and advance the road ahead," shared Woolpert CEO Scott Cattran. "This collaboration will enable our clients to yield the greatest value from their geospatial data investments and will help set the stage for implementing and managing smart city initiatives."

Cesium CEO Patrick Cozi said his company was excited to announce a partnership with Intel Geospatial to deliver specialized 3D geospatial solutions to enterprise customers across industries.

"Intel Geospatial deeply understands the value of AI-powered business insights gleaned from 3D geospatial data. Cesium is proud to partner with Intel Geospatial to unlock best-in-class 3D geospatial technology at scale for the Intel user community. Combining data management, visualization, analytics, and 3D tiling powered by Cesium, Intel Geospatial offers solutions for use cases like transmission and distribution in the energy industry, asset management, and remote inspection for insurance. The platform aims to expand access to geospatial insights beyond data scientists by designing solutions that are easy for anyone to use," Cozi said.

"We are proud that Intel is leveraging Enview′s AI to enable their platform′s 3D geospatial classification for faster turnaround of LiDAR analytics. Together we′re offering solutions for electric T&D, oil and gas, and governments to unlock geospatial insights at scale," said Enview CEO San Gunawardana. Enview is pioneering next-generation AI to automatically transform 3D data into insights at unprecedented speed, scale, and detail.

"The scalability of the Enview platform was a natural fit for the Intel Geospatial marketplace. Our team of experts in cloud-native processing of 3D geospatial data have pioneered leading AI specifically built for unstructured 3D data like LiDAR," he added.

Future market of GIS: The global geographic information system (GIS) market size is anticipated to witness consistent growth. This growth is attributed mainly to the rising use of location-based services across the industrial landscape. Organizations across myriad industries are becoming increasingly dependent on geographical information, in order to make sound decisions pertaining to resource allocations, market segment targeting, distribution network planning and emergency responses, among others. GIS technology is used predominantly for storage, management and analysis of data referenced spatially to the Earth. It is essentially a geographic method of spatial data analysis, designed to connect data with comprehensive information and enable enterprises to study maps and unveil hidden geographical patterns more easily.

Geospatial technology is establishing itself as an essential tool for organizations to collate different maps and remote sensing data and generate location-specific business models. The real estate sector, for instance, benefits greatly from GIS platforms, which can give potential homebuyers gain deeper insight into the area they are interested in. since these platforms involve several map layers, users can access details like distances to and from various amenities, school districts, and other area-specific information.

Based on a Global Market Insights, Inc. report, the geographic information system (GIS) market size is poised to exceed $9 billion by 2024.

The four major trends the market is going to witness are as follows:

Trend 1: Widespread applicability and advancements in location-based technologies: Location-based services are used extensively across a wide range of applications, including disaster management, mining, transportation, construction and urban planning, among others. For example, GIS technology is used extensively by facility managers to support a range of business processes and information systems for functions like building condition assessment, space use optimization and route mapping.

Rapid progress in geospatial technologies, including location-based data services, is anticipated to add impetus to geographic information system (GIS) industry dynamics over the estimated timeline. Moreover, the mounting use of cloud-based GIS platform is likely to further boost market growth in the years ahead. Cloud-based geographic information systems have gained traction among organizations mainly due to the complexities associated with the storage and management of location-based data, in order to achieve cost reduction, better productivity and efficient data management.

Trend 2: Penetration of GNSS systems in precision applications: With regards to component, the geographic information system (GIS) market from the GNSS (Global Navigation Satellite System) antenna segment is projected to depict a commendable 10% CAGR through 2024. This is attributed largely to the novel frequencies and signals emerging in modern GNSS platforms, which will position the products as crucial components in GNSS receiver functioning.

Professionals in the GIS sector are growing more accustomed to using handheld and geodetic receiver antennas in fixed-site and high-precision applications which require great positional accuracy. The penetration of GNSS technology in applications such as precision agriculture, construction, surveying, and marine, therefore is anticipated to augment GIS market trends over the coming years.

Trend 3: Strategic initiatives by prominent GIS industry players: The competitive landscape of the GIS industry is characterized by the emergence of numerous innovations in geospatial technology. Furthermore, strategic initiatives such as partnerships and product development are also likely to intensify competition in the overall business landscape.

To illustrate, U.S-based GIS & GPS software firm TerraGo inked a collaboration with CompassTools in January 2017, in order to provide advanced solutions for GPS & GIS data collection. The deal involved the deployment of TerraGo′s mobile data collection platform facilitated by CompassTools, featuring integrated support for software and hardware platforms such as Esri and Trimble.

Likewise, in 2020, Esri entered into a strategic partnership with OSI (Open Systems International, Inc.), to combine the benefits of both ArcGIS Utility Network Management by Esri and the monarch OT (operational technology) platform by OSI in order to deliver sophisticated real-time monitoring and GIS capabilities to various utilities.

Trend 4: Burgeoning development of sophisticated sat-nav technologies in North America: On the regional front, the North America geographic information system (GIS) market is anticipated to hold more than 35% market share by 2024. This growth is ascribed mainly to the rapid growth of geospatial technology, including the introduction of novel satellite navigation systems.

A notable example of this is NASA′s launch of next-gen weather satellites for NOAA (National Oceanic and Atmospheric Administration) in 2018. This development was initiated in an effort to enhance the accuracy of the GOES-S (Geostationary Operational Environmental Satellite-S) of NOAA, which provides detailed information regarding lighting, coastal fog, wildfires, storm systems and other hazards affecting the western U.S region.

In addition to these advancements, the presence of major entities such as Autodesk and Esri is also anticipated to stimulate GIS market trends over the estimated timeline.

What′S Next for GIST? For professionals with expertise in spatial technology and problem solving, the future looks rich in possibilities. In the years ahead, GIST will likely become an even more prevalent aspect of our daily lives, thanks in large part to the widespread adoption of smart technology and the IoT. As sensors capable of sharing spatial-temporal information appear everywhere from industrial equipment to coffeemakers, the volume of spatial data will grow exponentially.

Meanwhile, consumers and businesses will demand greater functionality and integration from spatial software applications. Ride sharing services and navigation apps have shown the public the power of apps that work with GPS and mapping platforms to give them real-time updates. These types of features could have growing uses for enterprises and governments as well when harnessed for purposes such as tracking assets and growing the reach of marketing campaigns.

The proliferation of spatial data and market for software means organizations will have a mounting need for professionals familiar with every layer of the GIS Technology stack. Data specialists will need to optimize their processes for collecting, cleaning and formatting spatial information. GIS software developers must also understand the full scope of the data resources they have available for creating spatial-powered apps to put that information to work.

Making Maps to Make Peace: Geospatial Technology as a Tool for UN Peacekeeping: *Geographic information has been noted to be the soldier′s most important weapon – second only to his gun. The mission experienced a lot of operational setbacks initially, because there were no topographical maps for accurate operational planning or orders and hence, it was easy for the Rebels [. . .] to ambush foreign peacekeepers who knew little about their area of operational responsibilities and had no maps.*

While anecdotal, these remarks, by Lieutenant General Daniel Opande, former Force Commander of the UN Mission in Sierra Leone (UNAMSIL), point to the importance of geospatial capabilities in contemporary UN peacekeeping operations. UN peacekeepers are harnessing geospatial technology, in particular satellite imagery and geographic information systems (GIS), as they carry out their mandated tasks.

The use of geospatial technology for peace and security was popularized by the actor George Clooney after his 2010 visit to Sudan. Together with Enough Project co-founder John Prendergast, he then launched the Satellite Sentinel Project (SSP), which used orbital satellites to document the locations of mass grave sites and razed villages in the Southern Kordofan and Abyei regions. SSP is a strong example of the advances made in this area by non-governmental actors. A more recent one can be seen in satellite images collected by Amnesty International revealing evidence of burned villages in northern Nigeria by Boko Haram militants. Within the UN System, too, entities such as the Office for the Coordination of Humanitarian Affairs (OCHA) and the UN Children′s Fund (UNICEF) have begun to employ geospatial technology to great effect, in such diverse areas as humanitarian assistance, refugee resettlement, food security and human rights monitoring. Additionally, the sanctions regimes under the auspices of the Security Council′s Panels of Experts have employed satellite monitoring for North Korea and Iran to determine the extent of their nuclear weapons development.

This part analyses how UN peace operations are harnessing satellite and GIS technologies. We argue that geospatial technology is strengthening the ability of peacekeepers to accomplish their mandated tasks. Beyond creating simple two-

dimensional maps of mission environments, geospatial technology has wide application and utility for UN peacekeeping. We identify eight tasks for which peacekeepers are effectively utilizing this technology: the demarcation and enforcement of international boundaries; support for the negotiation and implementation of ceasefire and peace agreements; stabilization and violence prevention operations; electoral assistance; the protection of civilians; human rights monitoring; support for the extension of state authority and the rule of law; and the provision of humanitarian assistance. However, it remains to be seen how and to what extent UN peacekeeping can continue to grow and expand its geospatial capabilities. We problematize its use by highlighting some of the challenges and barriers to implementation. Challenges of an operational and, mainly, political nature tend to impede the use of this technology. A key question in this regard is whether politics will prevent peacekeepers from harnessing geospatial technology. In analysing the issue, we maintain that these challenges are formidable but likely to be overcome.

Until the recently released ′Final Report of the Expert Panel on Technology and Innovation in UN Peacekeeping′, there has been little discussion on how UN peacekeeping missions are incorporating geospatial technology. Existing research usually falls into one of two camps. First, there is a small body of research demonstrating how geospatial technology can document mass atrocities and monitor human rights violations. This mode of inquiry tends to highlight the efforts of either non-governmental organizations or UN actors of a non-peace- keeping character, such as human rights and humanitarian agencies. There are also numerous reports released by NGOs themselves, such as the reports by SSP and Amnesty International previously mentioned, as well as Human Rights Watch, Harvard Humanitarian Initiative and several others, which use geospatial technology to gather evidence of mass atrocities and advocate for policy change by the international community.

Second, a growing body of literature exists on the role and effects, real or predicted, of new technologies on UN peacekeeping. It is widely accepted that the technological revolution will have a profound impact on the way peacekeeping is conducted (indeed, if it has not already). For instance, Paul Diehl theorized more than a decade ago that the potential impact of new technologies would include lowered human and financial costs of peacekeeping, improved surveillance and monitoring efforts, a reduction in troops and more nimble and less intrusive missions. Closely related to this is the discussion on the challenges of information and intelligence gathering in peacekeeping, and new technology is recognized as a vital tool for acquiring timely and accurate information. However, the above research tends to focus on either new technology generally (without detailed discussion of geospatial technology) or on high-profile technologies such as unarmed unmanned aerial vehicles (UUAVs), or drones.

We therefore see a clear need for an overview and analysis of the role of geospatial technology, particularly satellite imagery and GIS, as used by UN peace- keeping missions to further peace and security under the UN Charter. Undoubtedly, lengthy articles could be written on the role of satellite imagery in, for example, humanitarian assistance or protection of civilians by peace- keepers. While these are worthy areas of discussion, we broaden our analysis to touch upon the myriad ways peacekeepers are adopting these capabilities and, therefore, we hope to introduce some wider discussions about the use of satellite imagery and GIS to the discourse on UN peacekeeping.

It is also important to note what this part does not address. We do not discuss geospatial technology as field support. Peacekeepers rely on satellite and GIS information to improve their logistical planning and field support, for instance, by using it to identify sources of fresh water around which peacekeepers can construct their compounds, and mapping the accessibility (or 'trafficability') of roads during the wet season. In part because of these support functions, geospatial technology is sometimes associated more closely with logistics, information and communications technology, and field support rather than tasks accomplished in furtherance of peace and security. The fact that the UN Geospatial Information Section is located within the Department of Field Support (DFS) of the UN Secretariat is consistent with this perception. While these are worthy areas of discussion, and the line between front-end and back-end functions is admittedly blurry, we limit our analysis to how geospatial technology is strengthening the core mandated tasks of UN peacekeepers rather than field support writ large.

First, we begin with a brief background on how geospatial information is acquired, managed and structured within the UN Secretariat in the peacekeeping context. Second, we examine the uses of geospatial technology by peacekeepers in the fulfilment of their mandate, divided into eight general categories. In the third and fourth sections, we then turn to the challenges associated with peacekeepers employing this technology. Some are operational, but the most difficult to over- come are of a political nature, such as member state obstructionism. We then conclude and synthesize our argument, offering a simplified framework for determining when and under what conditions peacekeepers can effectively harness geospatial technology.

Research was carried out using qualitative methods, in particular semi-structured interviews and informal exchange of information with relevant actors, mostly at the expert and management level. Among them are UN staff at the Secretariat (in the Cartographic Section, recently renamed Geospatial Information Section, the Department of Political Affairs (DPA) and the Department of Peace- keeping Operations (DPKO)), in field missions, at the UN Logistics Base/Global Service Centre and at the UN Operational Satellite Applications Programme (UNOSAT), as well as member state representatives. The information collected was complemented with occasional participant observation in meetings held at the Secretariat, and subsequent analysis of relevant written documents, some of which are internal. As requested and to facilitate information sharing in the freest possible way, interviewees are left anonymous. Since the individuals most knowledgeable about this technology at the UN are on the 'production side of geospatial analysis, we are aware of the chance that our data might be biased in favour of the utilization of this technology. We attempted to address this potential bias by reaching out to the end users of geospatial analysis, such as political affairs officers at the Secretariat and in the missions.

Background

Geospatial technology refers broadly to a range of tools and capabilities contributing to geographic mapping and analysis, such as remote sensing, aerial photography, spectral satellite imagery, geographic information systems (GIS), global positioning systems and volunteered geographic information. However, we use the term geospatial technology in this article to refer specifically to satellite imaging and GIS, as these are used most frequently by UN peace-keepers. They are separate but interconnected technologies, and satellite imagery constitutes merely one element of a larger GIS system. GIS analysts use it in conjunction with other geospatially referenced databases containing information such

as topographic data, underground water exploration or conflict tracking. A satellite image may serve as the base map over which other datasets are layered to create a sophisticated and multi-layered product revealing patterns, trends and relationships among data and information over time.

Unlike UUAVs, satellite imagery has been used in the furtherance of the UN Charter since at least the 1960s. Cartography (the ancestor of modern GIS technologies) has likewise been employed by the UN since 1946, but it was not until 1951 that the UN Cartographic Unit was established with four cartographers and one unit chief. Thanks in part to recent technological advances, and following on recommendations from the 2000 ′Report of the Panel on United Nations Peace Operations (the Brahimi Report), the use of satellite imagery and geospatial technologies has been institutionalized in the UN System to such a degree that peace-keeping missions now regularly rely on them. As an example of how geospatial technology is considered ′low tech′, it has been described as ′2nd generation conflict prevention as compared to ′3rd generation and ′4th generation technologies such as crowdsourcing and open-source mobile phones.

How does the UN Secretariat acquire its satellite imagery and GIS data? The United Nations does not own its own satellites in space; there are no white satellites in orbit with the trademark ′UN lettering on the side. Instead, it has agreements with several government and commercial satellite providers, which grant permission for the UN to obtain images captured by their satellites. One of the most popular commercial vendors is Digital Globe, while France and the United States are among the most common government providers. Imagery may also be acquired indirectly through partnerships with other geospatial organizations, ranging from non-governmental actors (such as SSP) and commercial providers (such as Google Earth) to national geospatial agencies and the European Union Satellite Centre, which provides satellite imagery and analysis on theatres of shared concern. It is little known that the UN has a specialized agency, UNOSAT, devoted to providing satellite imagery and analysis to the UN System. UNOSAT was established in 2000 and is located within the United Nations Institute for Training and Research (UNITAR).

It recently made headlines by demonstrating through satellite imagery the scale of ′human suffering inflicted on the Syrian people in four years of conflict. In 2012, the majority of UNOSAT′s clients included OCHA and UN agencies such as the UN Refugee Agency (UNHCR) and UNICEF, which use this information primarily for humanitarian and refugee assistance purposes. Only 6 per cent of the agency′s requests for satellite imagery came from DPKO. Data for GIS are similarly acquired through mixed methods including open-source data, crowdsourcing, geophysical surveys and topographic data provided by UN agencies, governments and other partners.

Operating geospatial technology requires professionally trained geospatial analysts who can understand and interpret satellite imagery, are proficient with GIS software packages and are knowledgeable in feature analysis and data collection methods. In the Secretariat, geospatial information is managed by the UN Geospatial Information Section, situated within the DFS. Following the release of the ′Report of the Panel on United Nations Peace Operations in 2000, which recommended that ′GIS specialists should be assigned to every mission team, together with GIS training resources′,24 GIS units became a staple of large field missions, operating today in 15 of them. In addition to this presence at UN headquarters in New York and in the field, there is a GIS Centre located at the UN

Logistics Base/Global Service Centre in Brindisi, Italy, which also provides support to missions, especially those without a GIS presence, such as most Special Political Missions.

A Versatile Tool to Support Peacekeeping Mandates: By enabling peacekeepers to visualize data, improve their situational awareness and validate information, geospatial technology can help a mission fulfil its man- dated tasks in at least eight ways.

International Boundary Demarcation and Enforcement: One of the traditional uses of geospatial technology is providing technical assistance and guidance for the drawing and enforcement of international boundaries. Since peacekeepers who support boundary demarcation and enforcement are now deployed more frequently in internal rather than interstate conflicts, this function is not as central as it used to be, but the collection of evidence and the interpretation of contested data remain necessary. Such services were instrumental with regard to the border between Ethiopia and Eritrea, the Blue Line between Israel and Lebanon and the Green Line in Cyprus. The Geospatial Information Section also provided satellite imagery and technical support to experts drawing the boundary between Sudan and South Sudan. Then after the self-determination referendum in 2011 and before South Sudan′s official accession to independence, geospatial analysis helped monitor the evolution of Sudan′s military posture and understand whether Khartoum was building up a presence in the disputed areas.

Support for the Negotiation and Implementation of Ceasefire and Peace Agreements: When a peacekeeping operation is mandated to support the good offices of the Secretary-General, geospatial technology can prove useful to mediation efforts and ceasefire negotiations. The conflicting parties and the mediator must know with precision where to locate ground battle lines and corridors for the safe movement of each side. They need to be able to assess military gains not only in terms of the size of the territory occupied but also of its specific features, such as the presence of oil fields or other natural resources, and of access points such as seaports and airfields. As ′[p]arties to the conflict may have different views on the provided figures by the opponent′, these data must be verified by a neutral entity so as to ′establish a starting position accepted by all parties to the conflict'. Each issue negotiated must also be localized with precision, with internal UN guidance emphasizing that ceasefires should specify ′geo-locations for lines of disengagement, deployment, assembly points, demilitarized zones and monitoring positions′. For these reasons, it is recommended to mediators that every agreement be accompanied by ′[a]greed maps detailing these issues′.

Outside the UN peacekeeping framework, the use of geospatial technology to negotiate the Dayton Peace Accords in Bosnia-Herzegovina is particularly well documented. The mapping support team – which employed 55 people at the height of the negotiations – registered and digitized any proposed changes, providing computations about territorial percentages. This enabled the negotiators to make sure that no party gained a marked territorial military advantage. Geospatial analysis also helped assess the construction feasibility of the proposed corridor to the Muslim enclave of Goraž̌ de. Following the completion of negotiations, peacekeepers rely on geospatial data to track a ceasefire′s implementation and identify potential breaches. For instance, the GIS unit in the UN Mission in South Sudan (UNMISS) produces Cessation of Hostilities Implementation Maps in order to monitor compliance with the agreement contained in Security Council Resolution 2155.

Stabilization and Violence Prevention: Stabilizing fragile environments requires peacekeepers to deter threats and take active steps to prevent the recurrence of fighting. One way this can be achieved is through active patrolling and proactive deployment, which requires adequate military planning. By visually representing conflict situations and actors on a map, geospatial technology enables peacekeepers to plan for various contingencies and alter force distribution as needed. It can help them assess ′force to space ratios′, that is, the amount of security required to manage a given area under a particular set of circumstances. In the case of the African Union–United Nations Mission in Darfur (UNAMID), geospatial analysis showed that ′nearly half of all incidents occur more than 100km from the nearest team site′, a distance that falls beyond the range of most peacekeeping patrols and reveals the need to project a presence at greater ranges from the camps.

Geospatial technology can also increase the accuracy of conflict analysis by improving understanding of the drivers of violence. By overlaying several datasets and tracking changes over time, it makes possible the observation of relationships, patterns and processes to help make sense of complex situations. This technique was employed in the case of UNAMID, where it confirmed a strong correlation between the locations of traditional migration routes and inter-communal clashes between semi-nomadic groups, yet it debunked the assumption that such clashes moved north and southwards in line with seasonal rainfall patterns and the nomads movements. It was therefore recommended, as part of UNAMID′s strategic review, that peacekeepers take into account the locations of the migration routes when planning their patrols, irrespective of the status of the migration season. GIS analysis thus refuted aspects of conventional thinking about conflict dynamics in Darfur, which enabled the peacekeepers to better identify likely hotspots. This is consistent with the finding that combining several datasets offers more predictive power than simply using data on the prior outbreaks of violence.

Electoral Support : Assessing force to space ratios through GIS has also shown its usefulness when providing security assistance for elections and preventing election violence, a task which often falls into the hands of peacekeepers and UN Police. During the 2012 national elections in Timor-Leste, the GIS unit in the UN Transitional Administration (UNTAET) produced a map categorizing zones on a spectrum from ′no to ′high risk, based on where unrest had broken out during the 2006 elections, demographic data and the location of likely entrepreneurs of violence. This enabled UN Police to deploy preventively to the high-risk locations. Besides electoral security, geospatial technology is used for every phase of the electoral cycle including voter registration, the campaign period and election day monitoring and reporting. During the 2012 elections, UNTAET used Google Earth to map the locations of polling stations, which was used by the mission to disaggregate polling data by gender, age and political affiliation.

Protection of Civilians: Protecting civilians under imminent threat of physical violence is one of the primary goals of peacekeeping. Geospatial technology can help peacekeepers identify potential threats to civilians by increasing situational awareness and reporting on protection issues occurring in remote and inaccessible areas. In particular, the transmission of information in a timely manner is critical for early warning and detecting changes in military movement during a crisis. Ultimately, such information might help peacekeepers deter mass atrocities by denying potential perpetrators the element of surprise. This possibility was demonstrated by the early detection of a military convoy on

the road between the cities of Juba and Bor during the civil war in South Sudan. After the crisis broke out in mid-December 2013 and Bor was ransacked, there was a request to monitor a 200-kilometre stretch of road between the two cities. A satellite image taken on 10 January 2014 enabled geospatial analysts at UNMISS and in headquarters to identify a convoy of approximately 300 soldiers and 12 armoured vehicles heading towards Bor, as well as the construction of several military checkpoints along the road. This stood in sharp contrast with images taken in 2012, where Bor appeared as a non-militarized village. Given the direction of the convoy, it was identified as potentially belonging to pro-government forces. Six hours elapsed between the time the image was taken and when its analysis was presented to decision makers at UN headquarters and in the mission, including the Force Commander, Joint Mission Analysis Centre (JMAC)/Joint Operations Centre (JOC) and the Senior Management Group and crisis centre in New York. Used in combination with other sources, geos- patial imagery was able to improve the situational awareness of peacekeepers, giving them the option to take preventive action such as taking up strategic positions and protecting pockets of civilians.

In addition, satellite imagery and GIS are used to protect civilians by identifying the locations of landmines and unexploded ordnances and, based on societal impact survey data, where they are likely to be the most lethal. This helps the UN Mine Action Service focus its demining efforts on areas most in need of urgent rehabilitation.

Human Rights Monitoring: Geospatial technology is better known to the wider public for its use in documenting large-scale violations of human rights and humanitarian law. This has attracted media attention, in particular Amnesty International′s ′Eyes on Darfur initiative, and the SSP mentioned previously. Less well known is UNOSAT′s role in producing timely analysis in 2009 during the Sri Lankan civil war, which documented attacks on civilians by government forces. The agency′s work was also presented as evidence to the International Court of Justice for the conflict in Georgia, where imagery of destroyed villages corroborated reports of burnings by the Russian forces. Satellite images have also been reviewed by the International Criminal Court in the case of the Democratic Republic of the Congo (DRC), and by the International Criminal Tribunal for the Former Yugoslavia, in support of allegations of war crimes and crimes against humanity. This technology is therefore useful to peacekeepers as they monitor human rights and provide assistance in investigating, prosecuting and trying violations. For instance, UNMISS maintains a Human Rights Incidents Viewer interactive map. While such recording is typically used after an atrocity has already occurred, it might ultimately have a deterrent effect. It can be argued that if the conflicting parties are aware that their actions are being closely monitored in real time, they might therefore be expected to refrain from committing large-scale violations they could be held accountable for in international justice proceedings.

Extension of State Authority and Rule of Law: Deployed in fragile and failed states, peacekeepers are frequently asked to support the authorities, notably by fighting transnational organized crime, a task made easier by visual representation. A map produced for the UN Stabilization Mission in the DRC (MONUSCO) helped peacekeepers focus their patrols to deter smuggling across the border between the DRC and Uganda. The map gathered together in one visual outlet information on illegal crossing points, areas where smuggled goods could be concealed and potential helicopter landing sites.

Humanitarian Assistance : While the UN agencies are usually responsible for the provision of humanitarian assistance and disaster relief, peacekeeping operations are sometimes called upon to support their relief and recovery operations. This was the case with the UN Stabilization Mission in Haiti (MINUSTAH) after the devastating earthquake that struck the country in 2010. The peacekeepers relied heavily on the maps provided by the Crisis GIS Operation Team created at this occasion and coordinated by the then Cartographic Section. The maps it produced supported the assessment of landslide risk, the resettlement of internally displaced persons (IDPs) in new camps before the rainy season, the delivery of food, the management of debris and the assessment of damage and trafficability in view of the reconstruction efforts. A map showed the creation of an artificial lake threatening to flood the surrounding area due to a dam made of debris from the earthquake, and the US Army Corps of Engineers was mobilized to clear it. In South Sudan, the GIS unit provided time series monitoring on the movement of IDPs. Satellite imagery compiled between the end of December 2013 and mid-January 2014 showed the progressive destruction of the market in Bor and the simultaneous expansion of the IDP population within the nearby UNMISS base, until it was decided to construct a proper IDP camp on the outskirts of the compound.

Operational Limitations to the Use of Geospatial Technology: While we have demonstrated why geospatial analysis is an essential tool in the peacekeeping toolbox, it must be acknowledged that a number of challenges currently hinder the effective utilization of this technology, starting with the operational ones. These operational and implementation challenges can hinder its use in a given situation and reduce its overall effectiveness. However the value- added it offers may well outweigh the limitations, and many of these challenges can be overcome by a combination of technological advancement and reform of policies and practices.

Temporal Challenges: It can be time consuming to ′process a satellite image or GIS product acquired from a commercial provider, the length of which depends on a large number of variables. The amount of time it takes to generate a map turns on the availability of high-quality and reliable data, the complexity of the product in question (as measured by the amount of information or data layers needed) and the number of trained analysts. It also takes approximately two hours for Geospatial Information Section officials to access an image after it has been taken. For complicated GIS products that include multiple data layers such as ground water analysis or the locations of polling stations, weeks might be needed to construct a map (and even longer if data must be extracted from geophysical surveys or other means). One GIS official in the field lamented the

> *lack of man power and expertise for the extraction and digitizing of ground objects from satellite imagery, the collection and verification of spatial base data through field visits for the creation of new maps and updating of existing map products, satellite image analysis, [and] interactions with various clients who are requiring immediate services.*

Thus the time-consuming nature of data collection and image processing can be at odds with the time-sensitive nature of peacekeeping operations. Complex geospatial analysis is not well suited for kinetic and up-tempo situations where action often hinges on the swift acquisition of information and intelligence. In cases where peacekeepers are required to intervene in a timely manner to protect civilians or confront spoilers, this timetable poses obvious limitations, and alternative technologies such as UUAVs may be better suited.

No doubt for this reason the ′Final Report of the Expert Panel on Technology and Innovation in UN Peacekeeping recommended that the UN ′make more systematic use of commercial satellite imagery by enabling its near real-time sourcing and dissemination′, a suggestion also made by GIS personnel in the field.

Despite these drawbacks, a key temporal advantage of satellite imagery is that it enables rapid information collection from remote and distant areas, especially when compared to aerial reconnaissance or ground patrolling. This proves useful to gather information from inaccessible places, such as when roads are blocked or when security conditions do not allow the deployment of peacekeepers. This was demonstrated during the electoral crisis in Coˆte d′Ivoire in early 2011. Abidjan airport was reportedly closed down and the situation was too dangerous for peacekeepers from the UN Mission in Coˆte d′Ivoire (UNOCI) to investigate. However, it was necessary to find out whether peacekeepers were still able to use it as a supply route and whether the conflicting parties were able to rely on it as a port of entry to rearm and regroup. In these circumstances, geospatial capabilities were called upon by the mission leadership and the Integrated Operational Team at headquarters. Satellite imagery showed that no objects or heavy damage were obstructing the runway, leaving it open to international traffic. Without sending a ground patrol, peacekeepers were therefore informed that they, together with the Ivorian parties, could continue using the airport for supply purposes, contrary to the rumour.

Future advances in technology will allow for satellite imagery not only to be processed faster, with images sent more frequently, but for satellites to be autonomously tasked to collect images. Combined with highly sophisticated computer software and machine learning algorithms that can automatically identify trends and detect patterns, this will, in turn, facilitate quicker access and distribution of satellite imagery analysis across a mission.

Technical Challenges: Sun-synchronous satellites used for surveillance and cartographic purposes are not in unlimited supply. Those that do exist tend to cater to commercial interests or the geostrategic interests of the governments that operate them. Because there are a limited number of satellites in orbit above conflict zones, there may simply be no satellite overhead at the time something noteworthy is occurring. For instance, during the early stages of the conflict in South Sudan, a relatively small amount of satellite data was available, a reality that gradually changed as the international community paid greater attention to the ensuing conflict. In addition, because a satellite image is a snapshot representing a particular moment in place and time, it means that this technology is limited to situations where a specific area of interest can be identified in advance. Satellites are not effective at scanning the ground for signs of trouble, making the prospect of catching rebels ′red handed as they commit human rights violations difficult. At least theoretically, armed groups could also avoid detection by keeping a low profile during the hours when satellites regularly pass overhead (usually between 7 to 10am local time). Another related technical challenge is that satellites can only observe areas that are not obscured by heavy cloud cover, forest canopy or other climate and topographic impediments. This has made it difficult for satellites to penetrate heavy forest canopy in the eastern DRC and other African tropical regions.

Still, satellites are exceptionally powerful information-gathering tools. While previous generations of satellites lacked sufficiently advanced optical technology, today′s satellites can effectively capture an image from space hundreds of miles away with a high degree of clarity. Commercial satellites are capable of taking medium- and high-resolution

images, typically between 0.5–1 metres spatial resolution. This makes it comparable to the level of detail captured by aerial reconnaissance. Whereas the latter can capture highly detailed images over a smaller area, satellite imagery can document a much larger area and still observe such signs of conflict as destroyed villages, mass grave sites, the wreckage of exploded ordnances and tracks in the dirt made by heavy vehicles and transport. This is especially the case now that the UN has access, since March 2015, to imagery taken by Digital Globe′s World View 3, a satellite able to capture 0.3m-resolution images, which represents an improvement of four pixels to one. This notably enables analysts to distinguish between armoured and non-armoured vehicles, and to identify more easily the specific models of vehicles and artillery. From a cost standpoint, the price of satellite imagery is highly variable depending on the level of resolution and the time stamp of the image. However, for a UN peace- keeping mission, this is generally cheaper than other means of intelligence gather- ing such as deploying a helicopter or ground surveillance team, when costs of equipment, labour, fuel and maintenance are tabulated.

In the near future, it is expected that more commercially and government- owned satellites – with more flexible orbits as well as sophisticated video and sensory capability – will be launched into space, extending both the quantity and quality of images available across an ever-greater number of locations and moments in time. Already radar satellites and thermal infrared imagery technology can penetrate cloud cover but at higher cost and requiring more sophisticated technical training than optical imagery.

Cooperation Challenges between Information Requesters and Providers: A third challenge is cooperation between the UN Geospatial Information Section and other members of the Secretariat, including the Security Council. Without close collaboration, desk officers at headquarters may possess unrealistic expectations about what geospatial analysis can do, and they may fail to take steps that can assist geospatial analysts, such as ′geocoding or ′geotagging when reporting incidents of violent conflict. Furthermore, geospatial information without a corresponding political narrative can be unhelpful or even misleading, misrepresenting the timeline of events and skewing causal explanations for conflict. As such, close collaboration and information sharing among a mission, DPA, DPKO, the UN Operations and Crisis Centre and the Geospatial Information Section is required to harness this technology effectively. Lack of awareness of what the latter and GIS units can do for the Secretariat has been cited by UN officials as an impediment to the successful use of this technology.

Where collaboration does exist, however, geospatial technology can enable decision makers at headquarters to visualize complex information in ways that are simple and communicable. It is thus increasingly used in the Situation Centre′s briefings to UN departments, and in the latter′s briefings to the Security Council. In some cases, the data visualization this technology enables has proved more compelling than verbal briefings and written reports in catching decision makers attention and galvanizing action. GIS products used by the UN Assistance Mission in Somalia (UNSOM) and DPA as part of a Security Council briefing in 2011 revealed the expansion of the Somali transitional government′s estimated areas of control over Mogadishu between May 2009 and May 2011. This visual evidence was described as having a game-changing effect on the conflict narrative and the council′s deliberations.

Efforts are currently being explored to enhance intra-Secretariat cooperation as well as coordination between agencies, such as a possible memorandum of understanding

between UNOSAT and the Geospatial Information Section that would allow for closer collaboration. More education for staff on the applications of geospatial analysis is also being envisioned. This includes brownbag seminars with these entities as part of the ′Digital Diplomacy initiative, developing informal guidance notes on using technology in briefings, and the afore- mentioned report of the Expert Panel on Technology and Innovation in UN Peacekeeping.

Management Challenges in the Missions: A fourth challenge is managing the information workflow in the field so that geospatial analysis can find its way into the hands of relevant decision makers. Gaining better knowledge of a situation does not necessarily translate into appropriate action. The inability of the UN to ′effectively transmit [. . .] [and] analyze multiple streams of information from the field to headquarters and from subsidiary bodies to decision makers has been described as a major impediment to the UN′s efforts at early warning and conflict prevention.

Within missions, GIS units respond to requests for information from mission management, information analysis cells and other mission components. GIS cells may closely cooperate with the Joint Mission Analysis Centre (JMAC) or Joint Operations Centre (JOC), and they work closely with other information analysis units when applicable, such as the All Sources Information Fusion Unit (ASIFU) in the UN Mission in Mali (MINUSMA). Because geospatial analysis is primarily provided upon request, the challenge therefore is ′to get the tasking right′, in the words of one official who was a former GIS chief in a peacekeeping operation. According to another UN official, GIS units in the field have had to combat the impression that they are merely logistical or technical support components, in particular when they do not have a liaison officer in JMAC or JOC. In these cases, geospatial analysis may not be included in the mission′s regular intelligence management cycle nor feed into daily political and security briefings. This means that it is not necessarily taken into account by the mission′s leadership when making decisions, except for cases where good interpersonal relationships exist.

The perception of GIS personnel as logisticians may have to do with the fact that the Geospatial Information Section is nested under the Information and Communications Technology Division of DFS at headquarters. While GIS personnel are technically information officers, their role is substantially different from others in the ICT division who provide computer, internet and communications services. This was recently acknowledged by the Secretary-General, who proposed to rename the Cartographic Section as the Geospatial Information Section to ′reflect the expansion of its activities, from a map-production to an information-management entity that produces [. . .] sophisticated analytical products for use in the decision-making processes of the Secretariat′. Finding a suitable home for the Geospatial Information Section has proved difficult in the past: it has been relocated at least half a dozen times, at various instances finding itself under the DFS Logistics Support Division, the Department of Public Information and the Situation Centre. This self-described ′branding issue and ′identity crisis′ may be muddying the waters and generating further confusion about its utility for peacekeeping.

Political Barriers to the Use of Geospatial Technology: Although formidable, these operational challenges are less likely to hinder the use of geospatial technology than the numerous political challenges facing its advocates. Some states have expressed very strong opposition to the use of new peace- keeping technologies, and surveillance technologies in particular have been the subject of active debate among UN member states, the Security Council, troop-contributing countries and the Special Committee on Peacekeeping Operations, known as the C-34. It is important to note that during the course of this discussion, geospatial technology is not clearly distinguished from other forms of surveillance technology, such as UUAVs; statements by member states suggest that where peacekeeping is concerned, the subtle distinctions and nuances of various surveillance technologies are not always fully considered. To the extent that fears and concerns of member states towards surveillance technology generally apply to satellite monitoring as well, this is problematic. For reasons we explain, geospatial technology may be considered less politically intrusive and more likely to overcome political barriers to implementation than other forms of surveillance technology. Below we note some of the major political challenges to the use of surveillance technology as viewed by three key peacekeeping stake- holders: troop-contributing countries and members of the C-34; host governments; and the Security Council.

Discussions by troop-contributing countries and the C-34 have revealed major fault lines in the debate over whether the benefits of surveillance technologies out-weigh the risks. Notably, a chorus of voices has expressed concerns over the issue of privacy, confidentiality of information and data management and security. These include a number of stalwart troop-contributing countries such as Uruguay, Senegal, Philippines and Argentina; members of the Non-Aligned Movement such as Indonesia and Egypt; and permanent members of the Security Council including Russia and China. Venezuela, although not a peacekeeping contributor but a notable sceptic of what it views as a Western-led agenda, has been one of the most vociferous critics in the area, raising questions such as ′who had access to the information gathered through such technologies [and] how the confidentiality of such information was protected, especially when provided by private companies'.

Other countries such as Egypt and Malaysia voiced concerns about whether the benefits of new technologies can be equitably distributed among all troop-contributing countries. Wealthy countries tend to have the resources for procuring high-tech equipment, while troops from poorer nations deploy with sub-par capabilities. Malaysia noted that ′not all troop contributing countries are in a position to be equipped with modern technology and devices′, which could lead to a reliance on private companies to procure equipment and thus raise further questions about information security. This is epitomized in the case of the MINUSMA, whereby European contingents operate with high-tech capabilities including two intelligence, surveillance and reconnaissance units alongside Chadian forces in pickup trucks. Thus the proliferation of surveillance technology raises the possibility of a two-tiered system of peacekeeping contributors.

Related to this are questions over the accuracy of geospatial data and analysis. As the UN is often reliant on powerful member states for satellite data, some parties may question the data themselves as well as the accuracy of their analysis and interpretation, especially when they have reason to disagree with the findings. Moscow denied the authenticity of NATO satellite imagery taken in November 2014 showing Russian troop movements along the Ukrainian border. In the case of the Sri Lankan civil war, imagery taken by UNOSAT was dismissed as 'fake' by the Colombo government. In the past, data have

been misinterpreted or even deliberately manipulated. A famous example concerns former US Secretary of State Colin Powell′s 2003 briefing before the Security Council, in which he presented satellite evidence supposedly revealing Iraq′s possession of weapons of mass destruction. The allegations later proved to be false, which may have poisoned the well in this respect. This incident also raises concerns about relying too heavily on actors with vested interests in a conflict for information.

Countries hosting peacekeeping operations in particular may have reason to question the neutrality of the UN in this area. Although technology is more accurate and impartial than human monitors in documenting events on the ground, in reality it is rarely perceived as truly neutral. Satellite imagery is viewed with suspicion among some host governments who worry that this technology is being used for reasons that fall outside the Security Council mandate. They object to satellite surveillance (and other so-called intelligence-gathering activities) because they worry about what the UN or member states might discover with these tools. For example, they fear that satellites may ′reveal the location of military installations [. . .] or expose the incompetence or vulnerability of the government′. Rwanda, which neighbours a major UN peacekeeping operation in the DRC, has asserted that ′you can′t just put on blinders when it comes to surveillance. A satellite or UUAV operating in the DRC might point the camera at Rwandan or neighbouring territory. Rwanda called for a ′comprehensive and enforceable framework governing information collection and dissemination before it could support increased surveillance efforts.

Finally, the UN Security Council is a site of debate over the appropriate use of geospatial technology. Using satellite imagery to corroborate reports on the ground has proved controversial in the context of politically charged conflicts that implicate any of the five permanent members of the Security Council, or P5. Due to these sensitivities, the UN has had to tread carefully in its use of this technology. For instance, it has been reluctant to apply it in the case of the recent Ukraine crisis, likely fearing that this would be perceived by Russia as taking sides, thereby compromising the UN′s neutrality. It can be expected that a government′s attitude towards surveillance will depend on whether the findings are used in support of or against its objectives. In addition, with its traditional political culture and methods, the Security Council has been slow to embrace this technology in its briefings. Some council members view the use of satellite imagery, GIS maps and other visual aids with some scepticism and as a ′distraction from traditional means of reporting. The increased objectivity and data-gathering provided by geospatial technology – and what it can potentially reveal about UN actions on the ground – also presents challenges for an organizational culture that is ′not predisposed towards critical self-assessment′.

There is no question that these factors represent significant political challenges to the expansion of geospatial capabilities. However, there are reasons to believe that advocates of geospatial technology in peacekeeping can surmount these barriers. First, geospatial technology is perceived as less intrusive than other surveil- lance devices, such as UUAVs, therefore making sovereignty constraints less of a limiting factor. As Paul Diehl writes, ′[s]tates have shown a greater willingness to accept monitoring of activities from remote sensors or satellites than on-site inspections as they are less visible to the local population, reducing the possibility of ′cultural contamination and minimizing the appearance of government failure or foreign domination. Although Diehl was writing

before the use of the first UUAV in UN peacekeeping, his arguments about cultural contamination are all the more pressing in an era of UUAVs. Problematizing the role of drones in UN peacekeeping, Helena Puig Larrauri and Patrick Meier argue that the loud noise and visibility of UUAVs can stoke fear and confusion among communities they fly over and have a direct ′psycho-social impact′. The local population may assume that drones are weaponized, since ′a UAV from the ground is indistinguishable in terms of intent′. This is in contrast with satellites, which operate beyond site.

In addition, there is no sovereignty in space beyond a distance of approxi- mately 100 kilometres from sea level, as defined by the Outer Space Treaty of 1967. Since the altitude of orbiting satellites is much higher, they operate beyond a state′s territorial airspace and do not require authorization. In contrast, other surveillance technologies may not be permitted by the host government, depending on the Status of Forces Agreement (SOFA), which specifies rules of conduct and sets out the equipment and personnel that can legally be brought into the host country. On balance, geospatial technology may be preferred for being less controversial than some other forms of surveillance technologies, although this certainly will not alleviate all of the sovereignty concerns raised.

Second, despite legitimate concerns over where the UN procures its information, and the difficulty in providing assurances that data are accurate and valid, there are scarcely few actors considered more impartial than the UN in the area of geospatial analysis. This is especially true in the interpretation of imagery (if not its procurement). The Security Council and troop-contributing countries are more likely to put their trust in the UN than any one member state that has a clear vested interest in the outcome of a particular conflict or peace process. Even NGOs and humanitarian organizations, which operate independently, may be incentivized to overstate or radically interpret findings from satellite imagery to generate media attention and appeal to donors.

Third, practical investments in geospatial technology can mollify concerns over the creation of a two-tiered system of peacekeeping contributors. Compared to other technologies and equipment which may be owned and operated by specific country contingents, geospatial analysis is a mission-wide tool that falls under the control of the mission itself. This helps keep the force requirements for use of this technology relatively low. Whereas UUAVs may be brought to the field by specific country contingents (e.g. the Netherlands in MINUSMA) or by commercial contract in which private companies provide their own drone operators (as in the case of MONUSCO), an advantage of geospatial technology is that it is institutionalized within the UN System through the Geospatial Information Section, which has a presence in 15 field missions and can provide geospatial support regardless of the technological sophistication of any one military contingent. As a result, the benefits of geospatial information are democratized across the mission. The use of this technology is also bolstered by widespread support from Western countries, such as the USA, Italy, the Netherlands and Australia, which view it as an essential component for the creation of robust intelligence capacity for UN peacekeeping.

Conclusion: Geospatial technology, by which we refer to satellite imagery and geographic information systems (GIS), has wide application and utility for UN peacekeeping. It provides the unique ability to improve situational awareness and identify relationships, patterns and processes by overlaying data and tracking changes over time. This makes it a useful tool to draw and enforce international boundaries, support the negotiation and implementation of agreements, stabilize fragile environments, assist

electoral processes, protect civilians, monitor human rights violations, support the extension of state authority and the rule of law and provide humanitarian assistance. In turn, this can help peacekeepers make better informed decisions, including deploying preventively to high-risk locations and, in the best case scenario, denying potential perpetrators the element of surprise. However it will not transform peacekeeping; it must be considered as only one element of a larger toolbox, used to help peacekeepers monitor a situation of concern, cross-check data and contextualize and refine information, in conjunction with other technologies and traditional reporting methods.

It also remains to be seen how and to what extent UN peacekeeping can continue to grow and expand its geospatial capabilities. We have already addressed how challenges of an operational and, mainly, political nature tend to impede the use of this technology. In synthesizing the arguments made, therefore, one useful (albeit simplified) framework is to distinguish between the applications of geospatial technology at the strategic level versus the tactical level.

At the strategic level, it is inevitable that some governments will take issue with the UN′s involvement in this area, primarily by questioning whether the UN can safeguard geospatial data and ensure its veracity. To quote one official, ′[t]he strategic use of geo-images will ultimately be limited in the UN by the need to prove the end-to-end reliability of data′. Although the UN is arguably the most credible and impartial third party available, without being able to verify the source of its data independently, it will remain on shaky ground when it comes to using geospatial technology at the Security Council and other high-level forums. For geospatial data procured from member states, it can be argued that it is manipulated; for data purchased from commercial providers, it can be claimed that the data supply chain is not secure. Ultimately, the authority of data cannot be guaranteed, unless and until the UN owns and operates its own satellites and collects its own data, or without the installation of advanced information security systems that are currently only available to governments. This makes the use and expansion of geospatial capabilities at the level of strategic decision making an uncertain prospect.

Yet at the tactical level, it seems likely that peacekeepers will continue to harness geospatial technology. It is arguably less invasive and more palatable to host countries than other, more visible surveillance technologies such as UUAVs. With its low force requirements, it can be made available to all troop contingents and is therefore less likely to contribute to the creation of a technological hierarchy among troop-contributing countries. While there are operational challenges to implementation, such as the time-consuming nature of data collection and satellite image processing, these drawbacks would appear to be outweighed by the operational advantages. These include an ability to capture highly detailed images and gather information from remote and inaccessible areas, its relatively low cost and data visualization, which is often more compelling than verbal briefings and written reports. Future advances in geospatial technology, including more manoeuvrable satellites in orbit and automated detection systems, will allow for near real-time overhead visualization of mission environments.

Further research could examine in greater detail the intersection of geospatial technology and protection of civilians, stabilization or other core aspects of peacekeeping mandates. Equally useful would be a quantitative analysis of the various ways peacekeepers use GIS products. This might involve a numerical breakdown of the frequency with which they are employed in peacekeeping mis- sions, by whom and to what effect. It would shed light on the gap between their actual and potential use, and provide solid ground to

explore ways to increase mutual understanding and cooperation between GIS officers and decision makers. It would also enable member states to determine whether their fears of this technology are justified. Until that time, peacekeeping missions would benefit from exploiting recent advances in geospatial technology to carry out their mandate as effectively as possible.