Maps have always formed an integral part in decision-making processes as witnessed by elementary maps drawn on the walls of caves thousands of years ago. Over the last few decades, the use of locational or geographical information has exploded in commercial, governmental, academic, and individual enterprises. With the evolution of ever more powerful computing hardware and software, the ability to capture, manage, and spatially analyze geographical information has grown tremendously. In conjunction with the evolution of these geographically democratizing technologies, there has been an exponential growth in the use of spatially related information to support commercial, governmental, and academic decision-making processes for situations more complex than just deciding where to have dinner.

1.1 SPATIAL DECISION SUPPORT SYSTEM

1.1.1 Spatial Decision Making

- What Are Spatial Decisions?

A decision can be defined as a choice that is made between two or more alternatives. Individuals have to make many decisions every day. The potential choices in a decision are formed after defining certain minimum objectives, and alternatively, more demanding objectives. There are many examples of tools to help people make decisions, such as cost-of-living calculators for planning a move to a new city or retirement calculators that aid people in deciding how to invest for retirement. Institutional or organizational decision making is often much more complex, but individuals are still charged with making those decisions. There are greater resources in these decision-making situations but also a greater range of constraints, alternatives, and possible decisions. These people have to identify management goals and in turn determine a range of choices or alternatives that can meet those goals. In many cases, spatial characteristics and attributes are crucial to the decision-making situation. Imagine that you are planning a day off and you have to plan your itinerary. Most people will want to plan their trip along an efficient route, but might also make sure they get to eat lunch at their favorite restaurant. Thus, you need to process
Various pieces of information, including locational information, and make a choice about
your route that meets your goals as fully as possible. Today, with online tools such as
Google Maps, decision aids can be used to help support the routing decision. Now
imagine a delivery driver who has to make ninety deliveries the following day across a
medium-sized city taking into account traffic patterns. The sheer number of deliveries, as
well as traffic considerations, makes it difficult for that individual to decide on the exact
route that is most efficient. In these cases, computer routing applications are often used in
order to help plan efficient routes. The location of customers and businesses is clearly
important in the business world. Many consumers have noticed how businesses ask for
your address or ZIP code when purchasing an item. They are collecting locational
information about customers, for inclusion in databases that can be used to support
decisions about how to deploy their resources. Geographic information plays a vital role in
decision making by all manner of organizations. Approximately 80% of data used by
decision makers is geographically related (Worrall 1991). Over the last two decades,
amount of spatial information collected, managed, organized and analyzed has grown
greatly.

- **Spatial decision making problems:**

Before going into spatial decision making process, let us first understand what the
difficulties in spatial decision making are: Spatial decision making is a complex process
and requires information produced from many different sources and interpreted by a
variety of decision makers in relation to different goals and objectives. Typically, decisions
can be characterized as being structured (programmable), semi structured or un-structured
( non-programmable) (Simon 1960). Semi structured decision means they falls between
structured and un-structured. Problems related to these semi-structured spatial decisions
are multidimensional, have goals and objectives that are not completely defined and have
various alternative solutions. The difficulties of spatial decision making can be understood
with some examples. Let us return to the lake water quality issue that was mentioned
earlier. As example lake, sardar samand lake near to the city of jodhpur. This lake has had
consistently high nutrient level which helps in attracting countless migrating birds. A
major goal of some stakeholders is the improvement in the water quality parameters as
they adversely affect the ecological system of the lake, which in turn affects the recreational factors in the lake. On the other hand, the farmers, attempt to maximize profit, which leads to use various chemicals and fertilizers. All of these practices lead to runoff of pollutants inside the lake, thus creating water quality problems. Numerous government agencies have an interest in the lake and land in its watershed. These includes government tourism, natural resource management agency etc. thus, a large number of interested parties with different goals are there. Potential decisions made to improve water quality would require explicit consideration of spatial information, collateral details and would also require multidisciplinary scientific approaches. Let’s take another spatial decision example in continuation. Suppose, a builder is interested in constructing a new supermarket in the city. For that selection of suitable land for development involves several factors, like availability of land, cost, location, physical and geological characteristics of the land, proximity to utilities, target customers, other infrastructure and city ordinance. In situations like above, a computer based system can be a great help to decision makers for taking such critical decisions for optimal site selection.

- **Spatial Decision Making Process (SDMP)**

![Image showing the SDMP process]

**Figure 1.1:** General spatial decision making process
A process in which decision makers try to find the best possible way (solution) to move from an initial stage to the desired goal can be termed as spatial decision making process. Simon (1960) suggested that the decision making process can be seen as being structured in three phases: Intelligence, Design and Choice.

The foremost phase, Intelligence includes the formulation of the problem and searching for information relevant to find the solutions to the problems. The second phase i.e Design phase involves the compilation and analysis of the data and information to work towards a solution. The last and the final phase is Choice which includes selection from alternatives. This overall decision making process may be categorized in sub processes or stages as problem identification and goal specification, generation of alternative actions, identification of consequences of actions and selection of one alternative over the others (Huber 1989).

The most important factor on which a spatial decision making process depends is the information. Any kind of spatial decision making process requires adequate amount of information in order to participate in decision making process. Rarely is there enough or exactly the right kind of information is available. In 1999 Malczewaki categorized information used in spatial decision making process into two categories: “Hard” information and “Soft” information. Hard information is that which is derived from reported facts, quantitative estimates, or systematic surveys, where as soft information is that which is based on opinions, preferences and priorities of decision makers. Both sets of information are always likely to be considered in spatial decision making situations.

Another categorization of spatial decision making process is done by Keller(1997). He listed five steps governing the spatial decision making process: (1) Identifying the issue, (2) collecting the necessary data, (3) defining the problem including objectives, assumptions and constraints, (4) finding appropriate solution procedures, and (5) solving the problem by finding an optimal solution.

In our watershed problem, there are various parties having varied objectives. There are always multiple objectives arising from different parties perspectives and defining the relationships between the objectives and quantifying them in common terms is necessary. Ideally, the objectives could be minimized into a single overall objective. The most
difficult step in spatial decision making process is finding the appropriate solution procedure, from step 4. As the human and natural processes that occur in real world are not always easily defined, it is usually necessary to define multiple scenarios. For example, within the watershed problem, the amount of migratory birds coming to lake depends on various factors of land use practices. Such complicated situations require some model or combination of models to help evaluate these different scenarios effectively. In conjunction with all stakeholders, at this stage a set of software tools in the form of a formalized spatial decision support system, which would work with the database from step 2, should be developed. Although in this example, linear path is followed for above 5 steps, but in reality, in order to be successful, iteration between the steps in the process is required.

1.1.2 Need of Decision support system:-

As discussed earlier, spatial decision situations are complex, multidisciplinary, involves many stakeholders. Because of side variety of interested parties, it became more crucial to support and justify the decision made. In complex decision situations, the decision making process is iterative, interactive and participative (Goel 1999). By nature, spatial decision making situations are complex and ill-structured, thus humans individuals cannot process all the necessary collateral information present. Thus, in order to address complex spatial problems, support systems are often necessary, which can help in understanding the complex problem, from evaluation of the issue, provide formulation of possible actions, simulate consequences of decision possibilities and formulation of implementation strategies. The use of computer based tools for spatial decisions are necessary because complicated nature, requirement for accumulation, management, analysis of a variety of data sets etc.

During past two decades, a huge advancement in development and emergence of new technologies is observed. There are several tools, technologies or systems available to support spatial decisions such as GIS, DSS, Expert systems, remote sensing and spatial decision support system. In its simplest form, GIS can be defined as “ a computer based system for capturing, storing, querying, analyzing and displaying geospatial data (Chang, 2009)”. GIS cab ne considered as set of software tools that are used to create, manage, display and analyze spatial data for the purpose of modeling and investigation. With the
help of GIS creation, managing and analysis of variety of spatial and non-spatial datasets becomes easy.

In our watershed example, spatial data on land use, land ownership, planning and zoning, topography, hydrologic features, recreational lands and other information can be organized efficiently in a GIS database. With great benefits, comes some deficiency also. While GIS software tools plays vital role in spatial decision making, they lack the ability to adapt the decision making knowledge to the analysis, and software out of the box often is not flexible enough to allow analysis logic to be articulated.

DSS have been immensely developed over the course of last several decades with multidisciplinary aspect to support decision making*. They include analysis along with DBMS and user interface. The number and diversity of DSS have grown significantly with greater computing power. The drawback of DSS is that, they often do not handle spatial aspects of Decision making, thus extension of concept of decision support system to spatial decision support system has been necessary.

Remote sensing can be defined as the science, technology and art of obtaining information about objects from a distance (Aronoff 2005). Campbell in 2008 described remote sensing as “the practice of deriving information about the earth’s land and water surfaces using images acquired from an overhead perspective. Remote sensing is extremely valuable way of developing usable geospatial data for GIS and SDSS application. The main platforms for data collections in remote sensing are satellites and airplanes. Remotely sensed imagery benefits includes manual interpretation by mapping features on earth’s surface, repeated temporal recordings of the Earth’s surface for time-series analysis of changes, recording of meteorological conditions across large areas and over short time periods, and recording of wavelengths invisible to the human eye. As with GIS, the number of remote sensing instruments and use of imagery have grown significantly over the last few decades.

All of these technologies can play a crucial role in the development of SDSS. The GIS software often plays a fundamental and central role in SDSS. However, in order to truly support the spatial decision-making process, GIS functionality must be extended or joined with other technology, such as DSS and ES, in order to form true spatial decision support systems (SDSS).
1.1.3 Spatial Decision Support System- Definition:

The use of SDSS has grown dramatically over the last few decades, various authors have define SDSS is their own respective ways. Malczewski (1999, p. 281) defined SDSS as “an interactive computer based system designed to support a user or group of users in achieving a higher effectiveness of decision making while solving a semi-structured spatial decision problem.” In an earlier definition, Densham (1991, p. 405) stated that SDSS are “explicitly designed to provide the user with a decision-making environment that enables the analysis of geographical information to be carried out in a flexible manner.”

Leipnik et al. (1993, p.1) defined SDSS as “integrated environments, which utilize the databases that are both spatial and non-spatial models, decision support tools like expert systems, statistical packages, optimization packages, and enhanced graphics to offer the decision makers a new paradigm for analysis and problem solving.”

In a nutshell, SDSS are integrated computer systems that support decision makers in addressing semistructured or unstructured spatial problems in an interactive and iterative way with functionality for handling spatial and nonspatial databases, analytical modeling capabilities, decision support utilities such as scenario analysis, and effective data and information presentation utilities. As SDSS are multifaceted technologies that are manifested in many varieties, it is useful to look at some of the common traits that characterize them.

**SDSS Characteristics**

Goel (1999) discussed numerous traits that characterize SDSS: they are designed to solve ill-structured problems, they have user interfaces, they have the ability to flexibly combine models and data, they contain tools to help users explore solution space to aid in the generation of feasible solutions/ alternatives, and they can provide an interactive and recursive problem-solving environment.

While GIS provides modeling capabilities, they are not usually sufficient or directly applicable to unstructured spatial decision problems. GIS, while able to allow spatial exploration of the solution space, do not usually have sufficient flexibility for interactive
and recursive problem solving. In addition, GIS software is developed for spatial problems, while complex decision problems often involve both spatial and nonspatial aspects. As Keenan (2003) points out, an SDSS must cater to the overall problem representation, which will allow the user to not only incorporate the geographic data but also include structures and functionality for addressing the logical view of the problem.

**Figure 1.2: Characteristics of SDSS**

1.1.4 Origin of SDSS:

In the past three decades, SDSS have experienced tremendous growth and evolved from stand-alone desktop applications to Web-based and service-based SDSS. Research on SDSS has mainly originated from two different disciplines—DSS and GIS (Keenan 2006; Peterson 1998; Sugumaran and Sugumaran 2007).

Figure 1.3 demonstrates the overall progression of SDSS from GIS and DSS. Each discipline provided a unique contribution to the growth of SDSS. Before investigating the contributions of GIS and DSS, let us first understand the drivers or factors that governed the evolution of these disciplines.
1.1.5 Core Drivers for the development of Spatial Decision Support Technology

![Diagram](image)

**Figure 1.3:** Evolution of Decision Technologies (DSS, GIS and SDSS)

**Figure 1.4:** Core drivers for evolution of spatial decision support system
During the past three decades, significant progress has been made in the field of information systems, including the area of spatial decision support technologies. There have been many drivers spurring this progress, including advancements in information technology (IT) and communication technology (CT), the variety of users, application domains and experts in those domains, computer cost, developers/analysts, advancements in spatial sciences, commercial incentives in spatial industries, data affordability, data types, and data availability (Keenan 2003; Malczewski 2006). A schematic representation of the major driving forces involved in the progression of SDSS is shown in Figure 1.4.

Information and Communication Technology: Although there have been several drivers enabling the Progression of DSS, GIS, and SDSS, information and communication technology (ICT) has possibly had the largest impact. The continuous cost declines of computing power in concert with the rapid expansion of computer power have been the dominant technological drivers for the successful implementation of GIS, DSS, and SDSS (Peterson 1998). Computing advances have also facilitated advancement in other drivers, such as the types and number of users, user interfaces, and application domains. With the ever expanding computing power and increased affordability came a greater variety of users from a tremendous range of commercial, government, and academic disciplines. To meet the needs of these users, an expanded range of software applications and functionalities within these different disciplines were developed. Further enabling IT technologies such as the Internet, intelligent agents, multimedia, Web services and markup languages have also played a major role in the progression of SDSS over the last decade or so. The increased presence of the World Wide Web (WWW) along with advanced network technologies such as the Java language, ActiveX controls, Common Object Request Broker Architecture (CORBA), and the Distributed Component Object Model (DCOM) have also helped in the evolution of SDSS. In more recent years, communication technologies such as wireless or mobile devices and radio frequency identification (RFID) have also played a role in the progression of SDSS.

Spatial Data Availability: The growth of spatial decision support technology has also been driven by the availability and accessibility of spatially related data. Over the last few decades, there has been a surge in data availability. In the 1980s and 1990s, there was a huge effort to convert hard-copy maps to digital data through scanning and digitizing. Also over the last decades, the amount of spatial data derived from satellite and airborne remote
sensing as well as Global Positioning Systems (GPS) has grown greatly. One of the major reasons for this surge is the need for spatial data expressed by planners and managers from government agencies and business organizations (Keenan 2003). One estimate shows that up to 80% of data needed for the activities of business and government is spatially related (Worrall 1991).

Applications: Improved computer processing power and affordability led to the expansion of spatial applications into a variety of disciplines. Into the early 1980s, GIS and spatial processing software use was generally limited to those with high levels of computing and spatial sciences expertise. Primarily, this use was in academics and some government agencies. With the widespread development of desktop or personal computer-based systems with more user-friendly and standardized interfaces, the variety and number of GIS and SDSS consumers increased greatly. Many organizations, such as municipal and state governments, as well as a greater number of academic departments, started to recognize the potential of using spatial software such as GIS for managing data on spatial features, mapping purposes, and for addressing analytical questions.

Users, Developers, and User Interfaces: Spatial decision support systems can be utilized by individuals, groups, or entire enterprises. The evolution of hardware, software, and networking technology has led to a movement from individual expert-driven SDSS use to the inclusion of a much broader set of stakeholder

Expert Domain Knowledge: The complexity of issues in which SDSS are utilized often calls for domain or expert knowledge to be built into the SDSS to assist users. These systems attempt to capture expert knowledge, which can then be used in automated fashion within the system. By building domain or expert knowledge into an SDSS, more effective decisions by users regarding data selection, model selection, and scenario evaluation can be made.

1.1.6 SDSS Evolution:
This section summarizes the general evolution of DSS, GIS and also explains specifically how DSS and GIS evolved into SDSS. Gorry and Scott-Morton in the early 1970s defined a DSS as an interactive computer system that helps decision makers solve unstructured or semistructured decision problems using data and models. Alter (1980) expanded the DSS framework and discovers that it primarily consisted of the integration of three major
components (a) data management, (b) model management, and (c) dialog/interface management. The data management component used relational or other database technology to handle data that could be utilized in the system. The model management component handled analytical modeling capabilities, which utilized data controlled by the data management component. The dialog/interface component provided the mechanism for interaction between user and the system and allowed use of models and viewing of all outputs.

DSS traditionally support the decision-making process using three major components: a database, a model base, and a user interface. Spatial decision support systems are an extension of this DSS concept, with spatial data used for the analysis of decisions (Densham and Goodchild 1988; Keenan 2005; Jarupathirun and Zahedi 2005). Although DSS research and applications have a rich history, only recently have they commonly incorporated spatial data and analysis (Keenan 2003). This is despite the fact that it has been reported that 80% of the data needed for activities of business and government are spatially related (Worrall 1991). Thus, the advancement of DSS software to include spatial capabilities leads to development of SDSS.

The first large-scale use of a GIS-type system was the Canadian Land Inventory Project in the 1960s, which attempted to perform analyses to determine areas in different land uses and the possible future uses of different land areas (Keenan 2006). Later, several systems were developed, including a system called SYMAP, which was developed by the Harvard Laboratory for Computer Graphics and Spatial Analysis in the mid-1960s. The overarching technical evolutionary factors leading to increased GIS development in the 1980s and 1990s were the huge leaps made in computer hardware and processing speed (Malczewski 2004). In 1982, Environmental Systems Research Institute (ESRI), the largest GIS software company in the world, launched its first commercial GIS software called Arc Info. The personal computer-based Arc Info was introduced in 1986. GIS and mapping technologies began being presented in Internet-based technologies in the second half of the 1990s and into the 2000s. In the second half of the 1990s, numerous commercial (e.g., ESRI’s ArcIMS and GeoMedia’s WebMap) as well as open source Web mapping platforms were introduced. GIS functionalities are now being developed as distributable
components for delivery through the Web, on mobile devices, or through other distributed networked technologies.

Although GIS are characterized by many attributes that are crucial to SDSS, such as having spatial data management and analysis capabilities, they are, in general, not considered SDSS. The major deficiencies in GIS limiting their characterization as SDSS are the lack of analytical modeling capabilities (Segrera et al. 2003) and their inability to present effective scenario evaluation techniques. Malczewski (1999) pointed out that GIS, in general, do not provide the tools for presenting choices and priorities in regard to evaluating conflicting criteria and goals. These deficiencies limit the effectiveness of GIS in solving semi- or ill-structured spatial decision problems (Densham 1991).

![Figure 1.5: SDSS evolution. (Modified from Sugumaran and Sugumaran 2007.)](image)

### 1.1.6.1 Introduction Phase (1976–1989):

Initial phase in the history of SDSS development can be labeled as the introduction phase as this was the period in which explicit geographic components were first being included in decision support systems, GIS were being joined with other software or enhanced to form SDSS, and the term *spatial decision support systems* was first introduced.
There was an evolution in the literature from conceptual papers in the early years to more concrete implementation-driven articles later. The development of SDSS throughout the 1980s was often conceptual or commonly reviews of potential techniques (Carlson et al. 1977; Armstrong et al. 1986; Barbosa and Hirko 1980). Although the utility and initial acceptance of SDSS were evidenced by the literature though the end of the 1980s, there were a limited number of specific applications, mainly due to the fact that most spatial software systems needed large amounts of computing power, memory, and hard disk space. Furthermore, expensive hardware and software at this time required large budgets. In addition, the applications developed were characterized by GIS and other software that required a significant amount of expertise and were run only from command line interfaces. In summary, the introductory phase of SDSS development was characterized by the definition of conceptual frameworks for SDSS, prototype SDSS development, desktop or workstation SDSS with single users, and command line-driven user interfaces.

1.1.6.2 Integration Phase (1990–2000)

The integration phase witnessed many new technologies being integrated in SDSS and the development of SDSS growing quickly although often only in prototype formats. During this phase, three major areas of development or evolution were occurring in relation to SDSS: (1) expansion from single-user SDSS to group SDSS and collaborative SDSS, (2) inclusion of intelligent components in SDSS, and (3) the beginning of Web-based SDSS. Advances in these technologies led to an increase in the development and application of SDSS and to the integration of new techniques and technologies such as user-friendly interfaces, spatial models, intelligent components, and eventually Web-based delivery platforms into SDSS architectures. In the 1990s, the most common GIS software used in SDSS applications was ESRI’s Arc Info. Other GIS software used included Geographic Resource Analysis Support Systems (GRASS), MapInfo, IDRISI, and TransCad. Software such as Arc Info and GRASS were command line-driven and frequently run on UNIX workstations and consequently required a significant level of computer science and spatial science expertise. In the mid to late 1990s, software with more user friendly interfaces and increasingly robust functionality were developed, allowing GIS usage to reach a much larger audience. In the latter half of the 1990s, numerous SDSS implementations utilized
ESRI’s Arc View software, which possessed user-friendly interfaces as well as a proprietary development language called Avenue. This software was originally developed to be an application for viewing spatial data, but evolved into a more robust GIS when ESRI realized the tremendous potential number of users for an easier-to-use GIS package compared to their workhorse GIS, Arc Info. A wide variety of development languages and environments were used in the development of SDSS in the 1990s.

1.1.6.3 Implementation Phase (2000s)

The growth of SDSS has continued in the 2000s and has also diversified based on advances in Web, networking, and component-based technologies. The number of SDSS applications continued to grow rapidly after the year 2000. The movement from command-line-driven UNIX-based GIS software to personal computer-based GIS software with user-friendly graphical user interfaces (GUIs) that began in the second half of the 1990s continued into the 2000s.

In the last five years of the 1990s, Arc Info was still the most common software used in SDSS implementations, while Arc View was becoming used more frequently toward the end of the 1990s. In the first five years of the 2000s, Arc View became the most commonly used GIS software with Arc Info dropping to second place. The popularity of Arc View and its Avenue customization language appealed to many academics, businesses, and agencies that developed SDSS specifically for their own purposes. Advancement in desktop GIS software continued in the 2000s with the most prominent GIS software being used in SDSS changing to the next generation ESRI package ArcGIS after 2004.

A large number of other commercial GIS software (e.g., IDRISI, MapInfo, ILWIS), freely available GIS software (e.g., CommonGIS, GeoTools), or user-developed software with spatial processing/display functionality were also used in SDSS applications, but these other GIS software programs were applied in no more than 5% of the studies in the 2000s.

In the 2000s, there has also been tremendous advancement in the development of Web-based spatial technologies as well as component- or service-based spatial technologies. These advancements have increasingly been implemented into a variety of SDSS
applications. In the latter half of the 1990s and early part of the 2000s, Web-based mapping systems were being adopted, with ESRI’s ArcIMS, the University of Minnesota’s MapServer, and GeoMedia WebMap being utilized for spatial data presentation via the Web. These systems were often used for information presentation with limited analytical functionality.

Server GIS technologies, such as ESRI’s ArcGIS Server, provide spatial analysis and processing services over the Internet, allowing greater possibilities for a wider range of nonexperts to use these functionalities and allowing the development of Web-based SDSS. It is expected that these types of applications will grow greatly in the coming years.

Spatial decision support systems have evolved greatly over the last few decades based on advances in underlying technologies such as computer hardware and software, networking, and communication technologies. After early development in the 1970s and 1980s, the concept of SDSS gained traction in the 1990s. The development of SDSS became much more common in the late 1990s when ever greater amounts of digital spatial data were becoming available and personal computers were becoming widely used. The growth has continued into the 2000s with diversification based on technological developments. The development of SDSS generally followed developments in Geographic Information Systems, with many concepts and techniques of the science taken from decision support systems research and advances. The first SDSS were developed for workstations using command-line-driven GIS. These technologies were the domain of experts with high-end computing resources. In the 1980s and 1990s, the cost of computing consistently fell, leading to the development of the personal computer and software with graphical user interfaces.

Due to these advances, practitioners from a wider range of domains began utilizing computers and GIS software. The 1990s saw tremendous growth in the applications of SDSS to a variety of problem domains, including urban, transportation, environmental, natural resources, business, agricultural, emergency planning, and others. In addition, in the 1990s and into the 2000s, the development of object-oriented programming languages
and component-based software provided developers much more power in developing coupled and customized software.

Knowledge-based and artificial intelligence techniques were also introduced into SDSS in the 1990s. The great advances in networking technology and the use of the Web led to the increased use of Web-based technologies in SDSS architectures in the last decade. In addition, component-based software development, based on software and data compatibility standards, is providing greater flexibility in combining techniques from a variety of disciplines and programs. With improving wireless communication technologies, the ubiquity of GPS-enabled devices, and distributed software techniques, SDSS that operate with mobile components are becoming feasible. The combination of all these technologies is leading to an increase in Web based and mobile-based software components in SDSS, which provide greater flexibility for use of real-time data as well as the inclusion of non expert users in participatory systems. The rapid growth in SDSS development that began in the 1990s and has lasted until now should be expected to continue with a greater number of Web- and mobile-based SDSS being developed for a variety of disciplines.

1.1.7 Components of SDSS

Spatial decision support systems are characterized by a wide variety of approaches, application domains, development techniques, technologies used, and the complexity of the software configurations. However, to be considered spatial decision support systems (SDSS), they must contain certain components. These common components as well as how they are specifically included in SDSS and how interaction among the components is facilitated will be discussed in this chapter. The overall purpose of SDSS is to provide an integrated set of flexible capabilities for decision making for tackling semi- or ill-structured spatial problems. Spatial decision support systems should be designed for ease of use, to provide solutions through presentation of a series of alternatives, for flexibility of use and easy adaptation, and to support analytical methods. In order to achieve these attributes, there are several common components that every SDSS should possess. These include a database, spatially explicit models, user interfaces, visualization and reporting
capabilities, and alternatively, application domain knowledge. This chapter will provide an overview of the different components that compose an SDSS and how they interact. As spatial data management and analysis, usually with Geographic Information Systems (GIS), are often a focal component of many SDSS, a broad overview of GIS will be presented in detail.

**Components of Traditional DSS and GIS**

As discussed in earlier chapter, SDSS have evolved from DSS and GIS. Figure 1.6 depicts the combined components of GIS and DSS. A traditional DSS has three primary components: a database, a model base, and a user interface (Sprague and Carlson 1982). On the other hand, GIS can also be considered to be composed of three major components: a database, a user interface, and spatial data creation, analysis, and presentation capabilities. The database component within a decision support system (DSS) mostly deals with nonspatial data collection, retrieval, management, and analysis. This component usually does not support cartographic presentation or mapping functionality, which are essential to spatial decision making. On the other hand, GIS provides spatial and nonspatial data collection, storage, management, and cartographic display functionalities. The database component in both systems feeds appropriate information to the other components as needed.

![Figure 1.6: Traditional DSS and GIS components](image-url)
The model base component provides decision makers with access to a variety of models to help them in the decision-making process. The user interface component in both GIS and DSS facilitates the interaction between the user and the computer system. This component is important as unintuitive or awkward user interfaces can frustrate users and render an otherwise sound system inoperable. Thus, it is vital for this component to be considered carefully in conjunction with users of the system.

As seen in Figure 1.6, GIS lacks the necessary modeling capabilities, whereas DSS do not support spatial data analysis and cartographic display functionalities. The development of SDSS has evolved to utilize components from both DSS and GIS. The description of different SDSS components and their roles follows.

**Components of SDSS**

![Diagram of SDSS components](image)

**Figure 1.7:** Components of SDSS
As mentioned earlier, the spatial decision-making process involves (1) identifying the issue, (2) collecting the necessary data, (3) defining the problem, including objectives, assumptions, and constraints, (4) finding appropriate solution procedures, and (5) solving the problem by finding an optimal solution (Keller 1997). At the most basic level, there are four core components and one optional component of SDSS. Core components of SDSS include (1) the database management component (DBMC), (2) the model management component (MMC), (3) the dialog management component (DMC), and (4) the stakeholder component (SC) (Figure 1.7). The knowledge component (KC) is a common but not essential component in an SDSS. Figure 1.7 provides an overview of the components in an SDSS.

1.1.7.1 Geographical Information Systems (GIS) Overview

Following sections will provide a brief history of using spatial data and GIS software. It will also investigate some key concepts such as the definition of GIS, coordinate systems, spatial data models, spatial data collection methods, spatial data management, spatial data analysis and processing, and data visualization and cartography. Hence, describing the GIS component of SDSS in detail.

- History of Spatial Information and Data Use:
Maps have played an important historical role for thousands of years while spatial analytical techniques have developed substantially over the past two centuries. Ancient civilizations such as the Egyptians and Greeks were some of the earliest mapmakers. The Romans developed extensive cadastral (map-based property register) mapping to help manage their empire and to levy taxes on citizens (Bernhardsen 2002). Exploration and military purposes continued to drive mapmaking techniques and production. In 1838, the Irish government compiled a series of maps for railway planning, an effort some consider the first manual geographical information system (Bernhardsen, 2002).

The use of aerial photography and the development of photogrammetrical techniques advanced mapmaking after World War I (Bernhardsen 2002). The move from paper-based map use to automated digital spatial information systems began in earnest in the second
half of the twentieth century. In the 1960s, the Canadian government embarked on an ambitious project to develop a multilayer land use/planning map for analyzing areas in or available for forestry, agriculture, or recreation (Keenan 2006) using mainframe computers that by today’s standards were very limited. This system was called the Canada Geographic Information System.

However, with cheaper and more powerful computing power and memory resources, GIS development for PCs took off in the 1990s. The development of graphical user interfaces in the 1990s led to immense growth in the use of GIS in the 1990s, with Environmental Systems Research Institute (ESRI)’s Arc View being an example of a desktop-based GIS with user-friendly interfaces. The uptake and use of GIS technology has continued into the 2000s with networking and communication technologies leading to mobile and Web-based GIS developments. The growth in other geospatial technologies, such as GPS and remote sensing, has been commensurate with that of GIS in the last few decades. Indeed, the combination of these and other computing, communication, and networking and communication technologies has led to an explosion of spatially explicit applications in recent years.

- **Definitions of GIS**

  There is not a single agreed-upon definition of GIS. However, a review of several GIS textbooks shows some commonality in definitions of GIS:

  ✓ “A geographic information system (GIS) is a computer system for capturing, storing, querying, analyzing, and displaying geospatial data” (Chang 2009, p. 1).

  ✓ “[G]eographic information systems are systems designed to input, store, edit, retrieve, analyze, and output geographic data and information” (DeMers 2009, p. 19).

  ✓ “A GIS is designed for the collection, storage, and analysis of objects and phenomena where geographic location is an important characteristic or critical to the analysis” (Aronoff 1995, p. 1).

  ✓ “A computer-based system to aid in the collection, maintenance, storage, analysis, output, and distribution of spatial data and information” (Bolstad 2005, p. 1).
What makes GIS very powerful is the ability to explicitly handle spatial data as well as nonspatial data. Spatial data can take up a considerable amount of hard-disk space and require a considerable amount of computer processing power and memory. Over the last several decades, the great growth in computing power and accessibility to this computing power has aided the diffusion of GIS technology to a greater number of organizations. Spatial data have become an integral portion of many organizational databases being combined with extensive nonspatial datasets. A brief detail about the ways spatial data are stored, managed, and analyzed will be discussed in the following sections.

- **Coordinate Systems**
  Spatial data hold explicit locational information based on a defined reference system. Locations in the context of cartography and GIS are referenced to either a projected or geographical coordinate system, which is used to reference the surface of the Earth. A geographical coordinate system is one that represents locations on a model of the Earth with latitude and longitude coordinates. These geographical coordinate systems often use a spherical model to represent the Earth. A geographical coordinate system has the center of the Earth as an origin and measures latitude as degrees north or south of the equatorial plane and longitude measured in degrees east or west of the prime meridian (Chang 2009). Calculating areas and distances is complicated when using geographic coordinate systems since the distance corresponding to one degree of latitude or longitude varies depending on the location on the Earth’s surface. Also, in relation to paper maps, traditionally it has been impractical to carry around a spherical model of the Earth conveniently. Due to these complications, projected coordinate systems were developed by cartographers. Projected coordinate systems use map projections, which are techniques for representing the surface of the Earth on a flat, two-dimensional surface such as a paper map.

There are different kinds of projections, each with its own advantages and disadvantages. Each projection emphasizes the ability to accurately represent size, shape, distance, or direction at the expense of accurately representing at least one of these parameters. The ideal projection varies depending on the part of the world (i.e., at the poles or around the equator). When representing data in a small area such as a state, county, or small administrative unit, the distortions for a specific projection are minimal. However, when
storing information at the global scale, it is often more useful to use unprojected data, as any individual projection would incur large distortions. Map projections allow any point to be defined in a Cartesian x,y coordinate system. There are many different projections used throughout the world, and GIS programs often contain functionality for handling transformations between different projections and coordinate systems.

- **Data Models**

In order to represent the real world in a digital environment, models must be created that can effectively characterize real-world phenomena and reduce them to the binary (0 and 1) representation necessary for computer storage. Various digital models created to represent real-world objects in GIS and other spatial software applications exist. Although there are many individual ways to represent spatial data in a digital environment, there are two main types of data models used in GIS software: vector and raster. The ability to represent the spatial attributes of an object in a digital environment does not capture all aspects of the object. For example, you could represent a stand of trees as a polygon, but it might be important to also store information on the kind of trees or the approximate age of the trees. Another example would be the mapping of property boundaries. While it is useful to store the exact boundaries of the property, it is also useful to store information on the owner’s name, the address of the property, and the value of the land and buildings on the property. These types of information are called *attributes*. The combination of being able to store data on the geographic coordinates of features and also attributes of those features are what makes GIS a powerful tool and the backbone of most SDSS.

**Vector Data Model**

When using the vector data model, entities in the real world are divided into clearly defined features represented by geometry based on point, line, or polygon geometry. The simplest vector features are points that are represented by an x (easting) and y (northing) value and possibly a z value to represent elevation. Point spatial data can represent a wide range of features, such as a sign, a fire hydrant, a tree, a house, or even a town. At a less-detailed mapping scale, such as continent wide, features such as towns can be collected and represented as points. Lines are one-dimensional and defined by a series of x, y coordinates. The points in a line could represent the beginning, a break in, or the end point
of a line. The lines, as stored spatially, do not have any width. Again, depending on the scale of mapping and intended use, a road or river feature could be defined as a line or a polygon. At a continental scale, a large river would be defined as a line, but at a city level it might be defined as a polygon. A polygon is a two-dimensional representation of area defined by a series of points and line segments connecting the points with the start and ending point being at the same x, y location. A polygon is made up of connected, closed, and nonintersecting line segments

**Raster Data Model**
The second major data model category used in GIS is the raster data model. The *raster data model* is usually based on a regular two-dimensional grid that is used to represent real-world phenomena, with each cell in the grid representing an individual value for the characteristic being represented. The raster data model is useful for representing phenomena that vary continuously over space, such as precipitation, elevation, or soil erosion (Chang 2009).

**Raster versus Vector**
Due to the variety of real-world phenomena, both the raster and vector data models have advantages and disadvantages in their representation. The vector data model clearly matches some discrete natural and anthropogenic features in the real world better than raster data. For example, features with clearly defined geometry, such as roads, buildings, lakes, and so on, are more efficiently and accurately represented in the vector data structure. On the other hand, phenomena that vary continuously across space, such as elevation, climatic characteristics, air or water quality concentrations, etc., are better represented in the raster data model. If these phenomena were represented with the vector model, the number of individual features would be great, leading to large file sizes. Other real-world phenomena are somewhere in between discrete and continuous patterns. For example, depending on how real-world patterns are interpreted, land cover could be defined as discrete generalized polygons using the vector model or with a raster data model, which can capture small-scale variation in land cover through automated image processing techniques. The decision of which data model is to be used depends to a degree on the method for collecting or developing the spatial data.
• **Database Management**

One of the main strengths of GIS is the ability to store large amounts of nonspatial information that are either directly or indirectly related to spatial features. Pieces of information directly related to spatial features are called *attributes*. A wide variety of characteristics of any vector feature can be recorded in the attribute table of the vector feature class. For example, a line representation of pipe network attributes could include the material it is made of, diameter, date installed, manufacturer, and so on. There are a variety of ways to store spatial and attribute data, including the storage of both in the same file, in separate files or databases, and in a single relational database (Bernhardsen 2002). The advantage of the first method is rapid search capabilities, but with increasing amounts of data this method becomes less efficient. The second method stores spatial data in one file while attribute data are stored in a separate file with a feature identifier allowing them to be linked. The ESRI shapefile format (which is made up of anywhere from three to seven files) is an example, with the attribute data being stored in a .dbf (dBase format) and the primitive geometry data stored in the .shp file.

• **Data Considerations**

The collection of spatial data and the development of spatial databases should always follow a careful planning process. There are many considerations for developing suitable spatial and nonspatial datasets in a comprehensive database for a specific application. These considerations include the cost of data acquisition and management, the scale or resolution necessary, and the accuracy and precision levels required. Scale and resolution imply the amount of detail that is represented in the spatial data. The level of detail needed depends on the spatial decision problem. For example, a field-based precision farming operation would require highly detailed information on terrain and soil conditions. However, for a statewide assessment of land suitable for residential development, lower resolution spatial data on soil types or terrain would be necessary. Demers (2009) mentioned two primary types of errors, the first of which is mainly associated with vector data and is called an *entity error*.

Entity errors deal with incorrect spatial data, such as missing features, extraneous features, misplaced or misshaped entities, or misconnected features. These errors can be introduced
during the data creation process and should be checked while creating data either through manual checks or using topological tools of the GIS software. The second primary error type—*attribute errors*—can occur in both raster and vector data. If spatial analyses are carried out with flawed spatial data, then any resulting data will contain errors.

- **Vector Processing and Analysis**
  Many real-world elements are more suitably or efficiently represented as vector features. There are also many specific spatial processing and analysis techniques that have been developed specifically for point, line, and polygon vector data. These types of operations are Buffering, Spatial Overlay, Pattern Analysis and Spatial Statistics, Routing and Network Analysis.

- **Raster Data Analysis**
  A wide range of specialized data analysis and processing techniques operate on raster data. The simplicity of the raster data model allows a wide variety of operations to be carried out in a computationally efficient manner (Chang 2009). Operations involving raster data can be carried out on a single raster, on multiple raster datasets, or even with a combination of vector and raster data. In the latter case, the vector data is usually converted to raster data behind the scenes or unseen to the user before the desired operation is carried out. Generally, these raster operations can be classified into local, neighborhood, or zonal operations.

- **GIS Software**
  There is a wide variety of both commercial and open source GIS programs available with varying range of functionalities. Some of the most widely used commercial GIS packages that have a significant amount of functionality include ESRI’s ArcGIS, Intergraph’s GeoMedia, Pitney Bowes MapInfo, Clark Lab’s IDRISI, Manifold System GIS, and General Electric’s Smallworld. ESRI has generally held the largest market share with its GIS software. ESRI’s ArcGIS software is the product of evolution over several decades as ESRI has been producing commercial software since the early 1980s. Open source GIS software is in a phase of great growth presently. There are no open source GIS packages that have the amount of functionality that is available in some of the full commercial
packages mentioned above. However, some open source software packages have an impressive array of functionalities. One of the oldest and most extensive open source GIS software is the Geographic Resource Analysis Support System (GRASS). Many new open source GIS products are under continuous development with improvements and increased functionality being added. Some of the most popular include Quantum GIS (or QGIS), SAGA, uDIG, Mapguide and others.

1.1.7.2 Model Management Component

The model management component (MMC) of SDSS specifically helps to manage, execute, and integrate different models. Spatial models provide analytical capabilities to the SDSS and help in examining the locations, attributes, and relationships of features in spatial data through various overlay and analytical methods. The most existing GIS provide overlay functions but lack advanced analytical modeling capability. In recent years, a few GIS software programs have incorporated analytical spatial models. Examples of analytical modeling capabilities within GIS programs include a location allocation model in Arc Info, ideal point analysis in CommonGIS, and the analytic hierarchy process (AHP) and ordered weighted averaging (OWA) capabilities in IDRISI. In other cases, basic modeling frameworks, with specific user interfaces for developing spatial modeling processes, have been introduced in GIS and spatial analysis software. Modeling management frameworks built into GIS and other spatial analysis software include Spatial Modeler and Knowledge Engineer from ERDAS Imagine, Macro Modeler from IDRISI, and ModelBuilder from Environmental Systems Research Institute (ESRI). However, as these modeling frameworks rely on existing functions within the GIS, most do not provide users with the range of spatially explicit modeling capabilities necessary for complex spatial decision making. These modeling frameworks are growing in sophistication.

However, SDSS have traditionally and often still do require the development of a specific model management component that manages a set of models that interact with the spatial database and GIS functionality to produce new information relevant for the decision-making process.
1.1.7.3 Dialog Management Component

A key to any successful SDSS is the development of effective mechanisms for user interaction with software components. These mechanisms are termed the dialog management component (DMC). The DMC provides the interface between the user and the rest of the components of any SDSS. It provides mechanisms whereby data and information are input to the system from the user and output from the system to the user. As mentioned earlier, spatial decision-making processes involve iterative, interactive, and participative involvement of a decision maker or end users. The user interface components of an SDSS provide these functionalities and act as a channel through which the user connects to the computer system to generate and compare different solutions to a problem and to view potential outcomes from decision alternatives.

The importance of user interfaces has gained much attention in the past two decades, mainly because there has been a realization that usability is a key for the success of any software product. One can build an advanced SDSS that might solve complex problems, but if the user interfaces do not allow easy use, there is a high possibility for failure of the system. Some of the following characteristics should be considered during user interface design.

![Design of effective user interface](image-url)
In the design of an effective user interface, Malczewski (1999) summarized five issues that need to be considered: (1) accessibility, (2) flexibility, (3) interactivity, (4) ergonomic layout, and (5) processing-driven functionality. By accessibility, he meant that the user interfaces should be intuitive, facilitating new users’ applications. The ability to recover from unintended or mistaken actions would constitute a flexible system. An interactive system would allow efficient information flow back and forth between the user and the system itself. An ergonomic layout implies efficient communication between the user and the system. A processing-driven interface allows the user to understand the upcoming and completed tasks clearly. All of these characteristics can be met by careful planning of the system in advance with input from users, thoroughly documented and commented software code, and significant software testing by potential users.

1.1.7.4 Stakeholder Component (SC)

An important aspect of decision systems that is traditionally not explicitly discussed in DSS literature, and SDSS literature specifically, is the role of the stakeholders and decision makers. In a spatial decision-making situation, there are a wide variety of individuals and organizations that might have a stake in the potential outcomes. The successful application of an SDSS to a spatially dependent problem is dependent upon the effective involvement of a wide array of potential players. The different stakeholders function in various roles in the overall design, development, implementation, and usage of an SDSS. The general categories of stakeholders in situations where SDSS are applied include the decision maker or end user, the analyst, the developer or builder, and the expert. The expert has detailed knowledge in some crucial aspect of the spatial decision problem at hand and is familiar with the variety of techniques. The developer of an SDSS collects requirements from end users, designs system architectures, develops user interfaces, and programs the functionality of the system. The design phase of SDSS development is crucial and requires input from the full spectrum of potential stakeholders and users. The analyst is a person who is often involved in selecting models, carrying out simulations in the SDSS, analyzing data, producing outputs, and interpreting results, which are used to aid the decision makers. The decision makers are the stakeholders at the end of the process who need to be presented with meaningful information regarding various scenarios that deal with the
spatial problem at hand and that can be used to make decisions. The decision makers rely on the experts and analysts to provide useful information through the SDSS and meaningful interpretation in order to aid in their decision making.

Although these four separate roles in SDSS are somewhat distinct, there are often situations in which a single individual may operate in more than one role depending on the nature and size of the spatial decision problem and also the user’s level of expertise.

1.1.7.5 Knowledge Management Component

A knowledge management system (KMS) is not an essential component of an SDSS but has been included in many SDSS. The purpose of a knowledge management component (KMC) is to provide expert knowledge that can aid users in finding a solution to the specific problem or to provide guidance to novice users in the overall decision-making process and also in selection of analytical models. Knowledge management systems are computer programs that manipulate a knowledge base to solve problems. The knowledge component software is usually composed of a knowledge base, inference engine, and user interface. The knowledge base (KB) is composed of domain-specific facts and knowledge-based rules, which are used by the inference engine.

![Figure 1.9: Typical system architecture used in the knowledge management component](image-url)
The inference engine uses some programmed logic to make decisions based on those rules and facts. In order to develop a knowledge base, knowledge has to be acquired from experts and transformed into a set of rules and facts. The knowledge base is then analyzed by the inference engine to reach conclusions in the decision process. The user interface provides the link between the user, the knowledge base, and the inference engine.

There are numerous commercial, free, and open source knowledge base system shells for the development of knowledge-based systems. For example, CLIPS (C Language Interface Production System), JLisa, Mandarex, and TyRuBa are some of the free KB shells. Some of the commercial shells include Jess, EXSYS, Teknowledge, OpenRules, and Gemsym.

1.2 INFRASTRUCTURE MANAGEMENT

1.2.1 Infrastructure and Society
The success and progress of human society depends on physical infrastructure for distributing resources and essential services to the public. The quality and efficiency of this infrastructure affects the quality of life, the health of the social system, and the continuity of economic and business activity. A nation's economic strength is reflected in its infrastructure assets. Many examples can be cited from history. The Romans built a strong empire by constructing all-weather roads and viaducts throughout Europe, North Africa, and the Middle East to move people, goods, and water. In the colonial era of the 16th to 19th centuries, European nations emerged as strong ship builders and explorers. This was followed by the products of the Industrial Revolution, particularly in the use of steam engines for ships and rail road transport. Since then migration of rural-area population to cities and urban areas has been continuing because of higher-education institutions, diverse job opportunities, proximity to built infrastructure, and better quality of life [Uddin 12a]. Currently about 80 percent of the population in industrialized countries lives in cities and metropolitan areas Urban population is also vulnerable to natural disasters.

The historical development of the economic and social systems closely parallels phases of infrastructure development and urban growth. Demands on infrastructure and related
services increase as people expect a higher standard of life and public services. But, more importantly, Good infrastructure facilitates a higher quality of life.

A region’s infrastructure is a collection of public assets that can be managed to maximize public profit. It is diverse and distributed throughout the region, interacting in complex ways with the region’s people and landscape. Both private and public institutions have responsibilities for the system’s management. In other words, we can say that, Public and private agencies have always tried to maintain their infrastructure assets in good and serviceable condition at a minimum cost; therefore, they practiced infrastructure management.

However, as most of the nation’s infrastructure systems reached maturity and the demands placed on them started to rapidly increasing, infrastructure agencies started to focus on a systems approach for infrastructure management. The management task is beset by difficulties of data collection, measurement, and evaluation. This process has lead to today’s Infrastructure Management concept. In continuation to this, intricate collections of materials, infrastructure, machinery and people, with countless spatial and temporal relationships and dependencies, require progressively more sophisticated tools to design and manage them.

One milestone in the development of engineering management systems is the concept of integrated infrastructure management systems. This type of system is complex and mandates a need for integration and consideration of data sharing and security. The existing databases and data management system design traditionally have not been effective at allowing division within the departments of infrastructures to use or share data as extensively or as easily as should be the case.

One major reason for this lack of sharing has been that the spatial component of the data has not been effectively or correctly associated with the attribute data. This has led to problems in the quality, integrity, duplication, access, and availability of the databases. Spatial decision support systems (SDSS) are designed and implemented to address such
problems, with advanced analytical tools that help people explore a problem, and use the information gained for optimal decision making for Infrastructure management.

1.2.2 Spatial Decision Support System for Infrastructure Management:

Spatial decision support systems (SDSS) are designed to help decision makers solve complex spatially related problems. The use of SDSS in various domains of Infrastructure like transport, utility, academic, construction, business analyses, public health, and hazard analysis is increasing tremendously. For example, businesses are using sophisticated SDSS to analyze customer information for marketing, customer relationship management, and generating business intelligence to gain competitive advantage. Strategic Infrastructure Development is a necessary Component of economic development and vitality. For the same, requirements should be as effective and as efficient as possible in the Planning, Construction and Operation of Strategic Infrastructure investments.

Thus, spatial decision support systems developed using integration of focused technologies like GIS, RS and decision making can help us achieve these goals. Modern Infrastructure Projects are Complex Multi-Year Projects which require careful monitoring, coordination, and management. Require access to large amounts of data and information in real-time.

According to a study of US capital facility industry’s engineering information system, 40% to 60% of engineering time is spent locating and validating information. Effective data and information communication can reduce project delivery time by 20% to 50%. Poor communication between systems wastes up to 30% of project costs. Effective data management from the early project stages could save up to 14% of O&M costs. SDSS helps in smooth flow of information at every stage of development, which is the key of healthy infrastructure life cycle. In Fig1.10, transportation, one of domain of infrastructure management is considered and shown that how SDSS can helps in effective implementation. For construction and project management, with the use of GIS, multiagency coordination can be done from single point web GIS interface i.e. with the GIS interface, user can access project status, project financials, and project documents all
over web (Figure 1.11). With the use of these focused technologies in SDSS, efficient and effective development and management can be done.

**Figure 1.10:** Transportation Infrastructure lifecycle [Source: 2010 ESRI International User Conference - Technical Workshop, ESRI UC, GIS for Infrastructure Development and Management]

**Figure 1.11:** Project & construction management. Single point GIS interface [Source: 2010 ESRI International User Conference - Technical Workshop, ESRI UC, GIS for Infrastructure Development and Management]
1.3 ELECTRICAL UTILITY STRUCTURE

One of the primary contributions to the advancements and improvements in man's lifestyle over the years has been the ability to use and control energy. Electrification plays a prominent role in maintaining the standard of living. Energy demand has been increasing with burgeoning population coupled with intensive agricultural activities, industrialization and changes in living standards. Man’s use of energy can be seen in everyday operations such as mechanical motion and the production of heat and light.

A typical Power System consists of Generation, Transmission & distribution. Large amounts of power are generated at power plants and sent to a network of high-voltage (400, 220 or 110 kV) transmission lines. These transmission lines supply power to medium voltage (e.g. 10 or 20 kV) distribution networks (distribution primary system), which supply power to still lower voltage (0.4 kV) distribution networks (distribution secondary system). Both distribution network lines supply power to customers directly. Thus, the total network is a complex grid of interconnected lines. This network has the function of transmitting power from the points of generation to the points of consumption. The distribution system is particularly important to an electrical utility for two reasons: its proximity to the ultimate customer and its high investment cost.

To efficiently manage utility operations separate systems exist and the role of each system is different and unique. GIS (Geographical information system) is used to superimpose the complete electrical network assets from Generation to distribution on top of the land base data. GIS plays vital role in Electrical power system which leverages modern computing capabilities to deliver highly actionable information to a wide range of users, all while meeting the organization’s increasing need for real-time information. Advanced capabilities such simulation tools, network monitoring, Query shell, Technical Loss Calculations, analysis and energy forecasting can go far in giving utilities the power to be successful.

In the present days, many of the Electrical utility companies in India are facing problems due to high energy losses, reduced quality & reliability of supply, billing issues, theft of energy, no proper strategic revenue collection methods & representation, etc. This results
in inefficient operation, consumer dissatisfaction & loss of market value of the utility in public.

Thus, Reliable and sufficiently detailed data of existing network is required to facilitate decision making in all activities of the Utility System Management. Improving efficiency and reducing down time and controlling costs has become essential for a utility in order to be successful in the today’s highly competitive environment. With the huge & complex electrical distribution network consisting of many sources, feeders, alternate feeding points; updating and management of network data is a Herculean task.

![Electrical network super imposed on geographical land base](image)

**Figure 1.12:** Electrical network super imposed on geographical land base to perform network analysis.

As stated above a multi disciplinary, multi-attribute decision support system can assist in solution of complex problems and provide Efficiency gains in operational & non-operational areas of business such as fast operations, Reduction in response time, Customer Care, proper Energy Auditing & forecasting, loss calculations & most
importantly it helps utility sector for simple & effective visualization of complex distribution network. There are several tools, technologies, or systems such as SCADA (Supervisory Control and Data Acquisition) & DMS (Distribution Management System), GIS (Geographic Information System), AMR (Automatic Meter Reading), EABS (Energy Auditing & Billing System) available which can play a crucial role in optimal working of power sector. Thus, by integrating all the technologies with GIS, Spatial decision support system can be design and develop which can improves visualization of all the required information on Network Map with respect to location for better management.

Distribution is the weakest link in the chain of power supply. Distribution has been identified as the key focus area in power sector reforms. Ideally, T&D losses should be in range of 5-7%, but in India, T&D losses are in the range of 30-40%. This is the major factor of energy shortage. Some of the following areas shall be looked at to implement distribution reforms to reduce losses and improve energy efficiency. They are 100% consumer metering and AMR, Installation of capacitor banks & network reconfiguration, Feeder & DT metering, Total energy accounting, High Voltage Distribution System (HVDS), Effective MIS etc.

The support of IT and GIS in SDSS for Utility infrastructure is briefed in current paragraph. Enabling these focused technologies helps in achieving the above reforms (a) accurate up-to-date information of the entire network, (b) Electrical Network & Consumer mapping by physical pole to pole survey, (c) unique code for electrical assets like Substations, 11 KV feeders, DTs, Poles and LT feeders, (d) Technical attributes of the electrical network assets physically surveyed & linked with GIS map, (e) detailed door-to-door consumer survey for the creation of consumer database, (f) unique Consumer Index Number (CIN) provided to all types of consumers based on electrical address, (g) consumer database shall been linked with the network database for the purpose of defining the consumer's electrical connectivity, (h) This data shall be shared or exchanged with other systems (i.e. Network Analysis, Inventory, Trouble Call Management, Billing, Energy Auditing etc,) to know the actual scenario.

The ongoing reforms programme in the Indian power sector requires Information Technology (IT) to play a dominant role in institutionalizing the changes and
improvements. Here these focused technologies serves a dual purpose, i.e. Provides the platform for execution of business processes and Creates the information base for timely, effective decision making at the operational and strategic levels.

Various functionalities provided by GIS Application Software are –

(a) The changes in the network can be timely monitored, analyzed and correctly updated on a periodic basis.

(b) Network Analysis: Evaluate 33 KV, 11 KV and LT feeder-wise technical losses. Identify the network section overloaded or having high technical losses. Identify the area of unbalanced loading of DT and LT Network and take corrective action to minimize technical loss. Work out voltage regulation of the network and identify the areas having high voltage drops and suffering with low voltage problem. Using the GIS & Network Analysis software, virtually network shall be re-configured to minimize technical losses, voltage drop, over loading.

(c) Load Forecasting: GIS becomes an effective tool in optimal design and choice of substation location, demand-side management, future load assessment and load planning and load distribution.

(d) EABS (Energy Auditing & Billing System): The Computerized Billing System shall be implemented to effective and prompt customer billing system, which will provide tools to monitor control and process the revenue collection functions of the DISCOM.

(e) SCADA (Supervisory Control and Data Acquisition): SCADA system like an alert watch dog monitors utility network in real time and provides remote control of switching devices, transformers and equipments. Integration with GIS facilitates Utility to coordinate the maintenance and fault rectification activities of the distribution system with in less turnaround time.

(f) DMS (Distribution Management System): Supports operational improvements by using online network, data received from SCADA. Used efficiently to manage 11kV and below network, by providing planned switching orders and load flow analysis.
Figure 1.13: Distribution network representation in GIS & SCADA
1.4 SIGNIFICANCE OF PROPOSED RESEARCH WORK

One of the primary contributions to the advancements and improvements in man's lifestyle over the years has been the ability to manage its Infrastructure. Infrastructure management is an integrated, inter-disciplinary process that ensures infrastructure performance over its life cycle. It is an administrative process for planning, creating and maintaining the infrastructure. For any organization, management of essential operation components, such as policies, processes, equipment, data, human resources, and external contacts, for its overall effectiveness is required. Among other purposes, infrastructure management seeks to: Reduce duplication of effort, Ensure adherence to standards, enhance the flow of information throughout an information system, Promote adaptability necessary for a changeable environment, Ensure interoperability among organizational and external entities.

Geo-informatics is an advance technology and science which has emerged very strongly in past about 20 years, it includes Geographic information System (GIS), Remote Sensing, Global Positioning System, Communication, programming, statistics, geo processing, image processing, digital photogrametry etc. Geo-informatics uses geo-computation for analyzing geo-information.

GIS have emerged to meet ever-increasing demand of precise and timely information. GIS specifically would be best to be used in the present study for integration of various data sets and conducting spatial analysis for decision making. More recently, much attention has been paid to spatial analysis due to merging of geographic information system (GIS) and satellite images for designing and analyzing electrical distribution network. The conventional means are however, not only difficult and time consuming but also laborious. In extension to this technology, development of Spatial Decision Support Systems (SDSS) can help decision makers to solve complex spatially related problems and provide a framework for integration. Spatial Decision Support Systems are designed to help decision makers solve complex spatially related problems and provide a framework for integrating (a) analytical and spatial modeling capabilities, (b) spatial and nonspatial data management, (c) domain knowledge, (d) spatial display capabilities, and (e) reporting.
capabilities. The use of SDSS in Academic, Infrastructure and Business communities is on a rise.

Another primary contributions to the advancements and improvements in man's life-style over the years has been the ability to use and control energy. Electrification plays a prominent role in maintaining the standard of living. Modern civilization differs from earlier civilizations in the enormous use of inanimate sources of energy and mechanization of day-to-day activities. Energy demand has been increasing with burgeoning population coupled with intensive agricultural activities, industrialization and changes in living standards. Man’s use of energy can be seen in everyday operations such as mechanical motion and the production of heat and light.

A typical Power System consists of Generation, Transmission & distribution. Large amounts of power are generated at power plants and sent to a network of high-voltage (400, 220 or 110 kV) transmission lines. These transmission lines supply power to medium voltage (e.g. 10 or 20 kV) distribution networks (distribution primary system), which supply power to still lower voltage (0.4 kV) distribution networks (distribution secondary system). Both distribution network lines supply power to customers directly. Thus, the total network is a complex grid of interconnected lines. This network has the function of transmitting power from the points of generation to the points of consumption. The distribution system is particularly important to an electrical utility for two reasons: its proximity to the ultimate customer and its high investment cost.

To efficiently manage utility operations separate systems exist and the role of each system is different and unique. GIS (Geographical information system) is used to superimpose the complete electrical network assets from Generation to distribution on top of the land base data. GIS plays vital role in Electrical power system which leverages modern computing capabilities to deliver highly actionable information to a wide range of users, all while meeting the organization’s increasing need for real-time information. Advanced capabilities such simulation tools, network monitoring, Query shell, Technical Loss Calculations, analysis and energy forecasting can go far in giving utilities the power to be successful.
In the present days, many of the Electrical utility companies in India are facing problems due to high energy losses, reduced quality & reliability of supply, billing issues, theft of energy, no proper strategic revenue collection methods & representation, etc. This results in inefficient operation, consumer dissatisfaction & loss of market value of the utility in public. Thus, Reliable and sufficiently detailed data of existing network is required to facilitate decision making in all activities of the Utility System Management. Improving efficiency and reducing down time and controlling costs has become essential for a utility in order to be successful in the today’s highly competitive environment. With the huge & complex electrical distribution network consisting of many sources, feeders, alternate feeding points; updating and management of network data is a Herculean task.

As stated above a multi disciplinary, multi-attribute decision support system can assist in solution of complex problems and provide Efficiency gains in operational & non-operational areas of business such as fast operations, Reduction in response time, Customer Care, proper Energy Auditing & forecasting, loss calculations & most importantly it helps utility sector for simple & effective visualization of complex distribution network. Thus, the purpose of this research is to highlight the use of Spatial Decision Support System for infrastructure Management. And also, to study the Jodhpur city’s electrical distribution structure and propose a Spatial Decision Support System of the same.

1.4.1 Research Objectives: The objectives of the proposed research work are as follows:

a) To study Infrastructure Management and its various applications identified, also to investigate the major technological drivers so developed.
b) To study Spatial Decision Support System together with its evolution and treads over the last several decades.
c) To highlight the variety of SDSS application examples from a range of disciplines using a variety of techniques developed nationally and internationally.
d) To identify main components of a spatial decision support system, including the database, model base, user interface and knowledge components for managing infrastructure together with utility structure for the area.
e) Review the existing electrical utility structure of the area.

f) To efficiently design, develop and implement the domain level spatial decision support system (query shell) for infrastructure management of the area using various technologies such as, programming languages & development environments, Geographical land-base and overlaying electrical distribution network.

g) To Validate the developed spatial decision support system (query shell) with sample data

1.4.2 Thesis Structure:-

The structure of the thesis will be as in the following:

Chapter-1 Introduction- An introductory chapter deals with the background of Spatial decision support system, how spatial decision support system progressed from decision science & GIS together with main Components of SDSS. Background and significance of infrastructure management are also part of first chapter. Gives brief introduction about electrical utility structure too. It also includes significance of proposed research work and research objectives.

Chapter-2 Applications of Spatial decision support system: This chapter highlights the variety of SDSS application examples from a range of disciplines using a variety of techniques developed nationally and internationally. It also includes review of literature available on the topic.

Chapter-3 Study area and its electrical distribution network: This chapter briefs about the physical environment and economy of the study area. This chapter also includes details about human resources and city infrastructure. Chapter also gives detailed description about electrical distribution structure of the study area.

Chapter-4 Input data and Methodology for SDSS: This chapter includes details about data and collateral information so collected from various sources. This chapter also includes step by step description of Methodology used, database organization and standardization for spatial decision support system.
Chapter-5 Design, development and implementation of SDSS: This chapter includes identifying the main component of SDSS, brief details about the software and programming environment so used for development of SDSS. This chapter also includes designing of User Interface and step by step process for development of SDSS.

Chapter-6 Results: This chapter gives a detailed explanation of the result of applied methodology and development of spatial decision support system.

Chapter-7 Conclusions: Summary of the work is presented in this part along with conclusions and recommendations.