International Journal of Innovative Research in Engineering & Management (IJIREM)
ISSN: 2350-0557, Volume-9, Issue-2, April 2022
https://doi.org/10.55524/ijirem.2022.9.2.50
Article ID IJIR-2253, Pages 338-342
www.ijirem.org

Use of GIS in Road Infrastructure Development and Management

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ABSTRACT- GIS Architecture is an essential tool to be placed on comprehending the information of spatial and non-spatial data over a space and time. Rural Road Network comprises of group of nodes and links. The Network Configuration is a combination of these links with a directional orientation to the nodes which are the Centre heads of the habitations spread over the space. As most of the features are static in nature there is a need to Geo-Reference permanently and the dynamic interactions in terms of planning, construction, maintenance can be visualized over a time on this spatial frame. To create the rural asset, GIS is a great supportive tool which connects advance technologies and the conventional practices on a common platform. There is a need to decide the type of architecture which matches to the rural asset creation for display, reciprocate interactions, updating, data schema attachment and interfacing with advanced technologies.

KEYWORDS-GIS, Road Infrastructure, CGIS, Technology, Geographic.

I. INTRODUCTION

Geographic information systems (GIS) are also commonly known as geographical information systems. It was first developed in early 1960's, they were no more than a set of innovative computers based on applications for map data processing that were used a small number of government and universities [1]. Today GIS has become an important field of academic study, one of the fastest growing sectors of the computer industry and the most important and essential component of information technology (IT) infrastructure of modern society[2].

The word geographic in GIS carries two meanings:

Earth

Geographic Space

By earth it implies that all data in the system is pertinent to earth's features and resource including human activities. By geographic space it means to solve location, distribution, pattern and relationship within a specific geographical reference framework[3].

The history of GIS development started primarily in 1832 spearheaded by the French geographer Charles Picquet when he applied spatial analysis in epidemiology. Starting from there, John Snow used the method possibly meant as the earliest use of geographical method when he depicted a cholera outbreak in 1854 [4]. The advancements in technology that has been accorded as the history of GIS development made the present GIS as it is today. In the 20th century, the printing of geographic location was already made possible. However, the images are not yet considered to be vital as there are no databases to link them[5].

Canada then developed the first and rally operational GIS. It was called CANADA GEOGRAPHICAL INFORMATION SYSTEM or (CGIS) and was being used in 1960 to save, manipulate and study the data gathered for Canada Land Inventory[6]. It has been an improvement from the computer mapping software because it gives researchers the ability to scan, overlay and measure geographical places. The CGIS lasted up to the 90% but was never marketed as a product.

- By early 1980's a team of different companies surfaced as GIS software sellers as they have successfully combined the CGIS features with their upgraded development into it[7]. By the end of 20th century, the growth of GIS platform and system has been rapidly spread that many users are already weaving GIS data using the internet. Right now, there are available customised platforms of GIS that performs many different tasks making applications and geospatial data are already available in the internet [7].
- **Non-Motorised Vehicles**
  Non-motorized vehicles are generally pedal powered vehicles, having different shape and size which are used to transport passengers as well as goods [8]. The non-motorized vehicles are slow moving vehicles consist of cycles, cycle rickshaws, hand carts, horse carts and bullock carts. In India, there is heterogeneous or mixed traffic where motorized and non-motorized vehicles flow together, so it is essential for traffic engineer to understand some of the characteristics of these non-motorized vehicles [9].

II. FUNCTIONAL COPONENTS OF GIS

GIS converts data into useful information. The functional components of GIS follow the lifecycle of data from creation, storage and eventually to analysis and presentation[10].

A. Data Capture System

The data with geographical reference is taken care in the system. For example, topographic mapping organisation envisages to convert all the hard copy maps into digital format, also require conversion of not only the map feature but also the associated attributes mentioned as text in the printed map culminating into database[11]. for instance, road features extracted from the image and their geometry and several semantic attributes have to be stored in the database which involves sub-tasks:
Scanning
Image processing
Subsequent interactive editing
The system also takes care of the data administration also, it needs some analysis function (e.g.: to find out all road segments indeed connect in a topological way, and if not, to perform the creation of topology)

B. Administration System

The main focus is to store spatial and non-spatial data for long term use and maintain it for any time usage. The system is also responsible for updation of the system and keeping it up to date. E.g. land information system that has to keep such data available for years and decades. They administer the data. Analysis, functions and presentation functions help in the maintenance of such administrative systems[12]. In this case also there is prime responsibility of this sub-system i.e. to manage data for long term use with minor dependence on three other sub-systems for data capture and data visualization.

C. Analysis System

The execution of several types of spatial and non-spatial analysis. The analysis performed transforms the data captured by the data capture system, stored and maintained by administration system to useful information for the visualization.

D. Presentation System

At the top of the entire GIS acting as an interface between the end user and the system[13]. It provides graphical visualization of the entire system. The fictionalities of this system includes interaction with the map by zooming in or out, planning and selecting and deselecting layers. Apart from this, it also provides data to the other three components for their functions. Display of maps for editing to the data capturing system, for display of the outputs generated in the analysis system and vice versa. It is dependent on the other three system[14]. Also, it needs data capturing, administrative and analysed functions to a certain extent.

III. GIS DESIGN

Design of GIS consists of modelling of real world phenomenon to assist in better decision making for planning, monitoring and management of various spatial activities. There are basically two types of models that are used in GIS, they are

- Raster model
- Vector model

Like any information system where it is the application which plays the major role, same is this case with the design of GIS also. The application is the top of the design of GIS which in turn is generated from the need / requirement and feasibility studies. Application and development process are specific to the organisational needs. Application requires data which in turn is managed by the database management system. The hardware and software are the integral part of GIS design and are inter dependent on each other. There are functions in the application domain of the design which performs the desired operations. The basic approach to the design of GIS is shown in Fig.1:

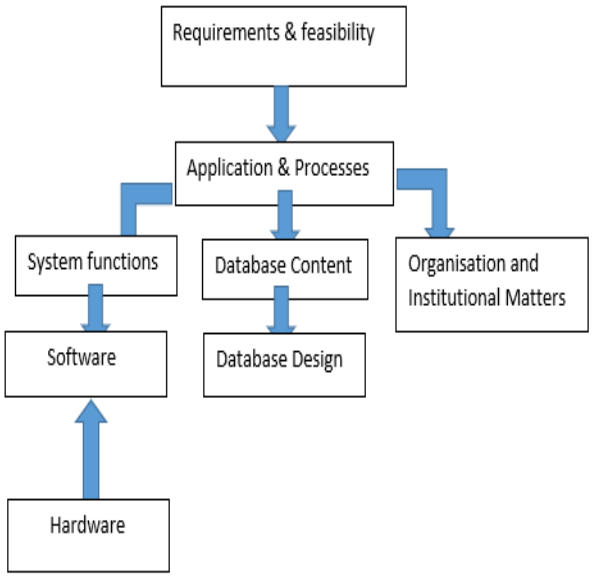

Figure 1: Basic Approach of GIS

IV. DATA USED IN GIS

GIS requires spatial data and non-spatial (attribute) data for furnishing much needed information to the decision makers / Executives. It is about location and relationship of various geographical features of earth. Human eye and mind work simultaneously to identify the location of the object, its spatial arrangements and relationships easily. The computer cannot do the same. The spatial data has to be modelled in such a way that the software should allow the entry of spatial data; also understand their spatial location and underlying relationships. This has to be done meticulously keeping in mind retrieval of stored data for future use.

A. Spatial Data

Non- Spatial Data (Attribute Data)

1) Spatial Data

Spatial data are characterised by location of real world objects, connection with other features. Spatial data can be stored in both raster and vector format. All GIS software has capability to store and process spatial data.

2) Spatial Data Models

Conversion of real world into discrete objects is done through data models. The spatial features of terrain are presented in GIS

through various data models and organised in a series of data sets or layers in GIS environment. There are two popular GIS data models viz. RASTER and VECTOR DATA MODELS. In raster data model, the spatial features are stored as pixel or set of pixels in the form of rows and columns while in vector data models spatial features are stored in three basic units i.e. point, line, polygon. Raster models are useful for storing data that varies continuously, as in an aerial photograph, a satellite image, a surface of chemical concentrations, or an elevation surface. The vector model is useful for describing discrete features, but less useful for describing continuously varying features such as soil type or rainfall pattern of the area and corresponding catchments.

3) Raster Data Model

In raster representation of spatial features, the surface is divided into a regular grid of cell known as pixel. Raster models are useful for storing data that varies continuously, as in an aerial photograph, a satellite image, a surface of chemical concentrations, or an elevation surface. In raster type of representation of the geographical data, a set of cells located by coordinate is used; each cell is independently addressed with the value of an attribute. Each cell contains a single value and every location corresponds to a cell. Aerial photos and satellite image are commonly used for of raster data, with one primary purpose in mind: to display a detailed image on a map area or for the purpose of rendering its identifiable objects by digitization.

4) Vector Data Model

Vector data model uses line, segments or points represented by their explicit (X,Y) coordinates to identify locations. Discrete objects are formed by connecting line segments which area is defined by set of line segments. The vector model is useful for describing discrete features, but less useful for describing continuously varying features such as soil type, or rainfall pattern of the terrain. Modern GIS packages are able to handle both models. In GIS geographical features are often expressed as vectors, by considering those features as geometrical shapes. Different features are expressed by different types of geometry.

Points

Defines discrete locations of geographic features too small to be depicted as lines or areas. Such as telephone poles, well locations, stream gauges. Points can also represent address locations, GPS coordinates, or mountain peaks, areas when displayed at a small scale.

Lines or Polylines

One dimensional lines or polylines are used for linear features suvh as rivers, roads, rail roads, trails and topographic lines. Again, as with point features linear features displayed at a small scale will be represented as linear features rather than as a polygon. Line features can measure distance.

Polygons

Two dimensional polygons are used for geographical features that cover a particular area of the earths surface. Such features may include lakes, parks, boundaries, buildings, city boundaries, or land uses. Polygons convey the most amount of information of the file types. Polygon features can measure perimeter and area.

Each of the geometries is linked to a row in a database that describes their attributes. e.g: database that describes lakes may contain

- Lake's depth
- Water quality
- Pollution level

Thus, the respective information can be used to create a particular dataset. i.e. the lakes could be represented on a map based on the level of pollution.specified traffic conditions at a certain time[15]. After plotting the fundamental diagrams for each location, the value of maximum flow in the flow-density curve is taken as the capacity of the section.

B. Non-Spatial Data

Non-spatial data or attribute data describing the characteristics of spatial data. These datasets are stored and managed in a separate attribute table. Maintaining attribute table independently from the spatial data increases its flexibility. GIS software has the capability to link the spatial data with corresponding attribute table. The link is established by using a unique entity identifier, that exists in both spatial and attribute data table.

C. Sources Of Non-Spatial Data

- **Government Reports/ Records**

Govt. departments functioning at various levels collect data while implementing developmental programmes and document them for onward transmission to higher authorities of the respective departments. This is one of the most important sources of attribute data. There are service departments like education, public health, panchayat development, ground water, forest etc.

- **National Informatics Centre (NIC)**

NIC maintains official data collected by various departments at village level and consolidate them at district level at NIC district centres; it is further consolidated at state level. They are available in spread sheets. Therefore, opening and using them in MS Excel software is possible.

- **Census of India**

The Indian census is the single largest source of a variety of statistical information on different characteristics of the people in the country. with a history of more than 130 years, this reliable and time-tested exercise has been bringing out a valuable wealth of population statistics every ten years.

- **Statistical Year Book**

Ministry of statistics and programme implementation has published statistical year book-2014 of India covering all sectors with national and state wise details. The users can easily excess and download the data in MS excel format at free of cost. (www.mospi.nic.in)

- **Data Meet**

A united states-based firm producing data in various forms and levels based on google, wiki map informatics and users of google which with the help of internet facilities helps in uploading new data and keeping all uploaded data up to date.

- **Open Sources**

Various organisation carries out survey independently for the execution of their own programmes as mobile telecommunication, power cables and transmission towers,

hydro-potential surveys (SHP's) develop a statistical record on their own and can have used by other agencies by their GPS locations.

D. Role of GIS in Planning, Designing, Maintenance and Monitoring of Roads

GIS in Rural Roads is having a multifaceted application at various stages in planning, designing, construction, maintenance and monitoring of the rural assets[16]. There is a need for generating a transparent approach which is founded on topographic sheets, ground truth verifications, cadastral maps and satellite enabled mapping either by GPS or satellite. The common approach is given below:

The Geo-Fenced map display system is essential because of the following reasons

- To identify the progress of roads in reference to access and connectivity pattern for overall development of the rural areas.
- To locate the habitations of different ranges be it Geo-referenced, which will helpful for policy making on connecting habitations over a time frame.
- To avoid multi-connectivity among the habitations rather the basic objective of scheme can be analysed.
- To identify rural growth corridors and tracked the density of roads constructed per block / constituency / district / State which may be helpful for fund allocation with justification.
- To overlay the land use, terrain conditions and other obligatory aspects, a Geo- reference of map display system will be helpful for scientific and engineering design.

E. Implementing GIS in Infrastructure Management

- **Step 1**

Procurement of consistent topographic sheets like 1:50,000 and scan them with the defined resolution suggested. Digitize them with a defined zoom level such that all the features can be digitized in number of layers.

- **Step2**

Conducting the GPS survey for all the ground control points of every district on the known roads / important places to a minimum number of 25-50 per district.

- **Step 3**

Geo-fenced that topographic and mosaic them with the administrative boundaries of the district and the State by taking the output of Step 2. This leads to a resolution correction to a length of plus or minus 5 m.

- **Step 4**

By using the GPS instrument all the habitations are to be Geo-coded with the minimum number of satellite linkages of 9-10 number.

- **Step 5**

By using the navigational mode of GPS or by static GPS record all the curves and road length of each road with a specific record of culverts, village starting and end points, starting and end points of type of road and all other obligatory features of the road. This survey will give alignment, villages covered, the type of surface covered and length of the road to precision.

- **Step 6**

Use software inter-phase which should be the common interface matching to the national level mapping and to display all the spatial and attribute data about – the road, habitation, support infrastructure and land use, administrative/ constitutional boundaries of the State.

- **Step 7**

The outcome of this study will give a straight answer with graphical accuracy

This output will be useful for the following reasons like:

- Core Network verification.
- Planning of New Connectivity and Prioritization of Upgradation.
- Identifying the rural growth corridors.
- Neighbourhood network analysis with Core Network.
- Analysing the Non-Core Network
- Mapping the rural road network scenario at the National level
- Display of all the habitations ranging from 100+ to 1000+.

The physical progress and the characterization of the network developed by this scheme with left out habitations or newly eligible habitations are required to be spatially mapped for future transparency in sanctioning the roads. Also, Identification of high access roads to the different production and attraction centres; rural growth corridors; inter-transport networks; and roads for inter modal coordination will always improve the road transport. There is a need to study on network analysis with non-core network and other functional roads by considering the land use, socio-economic and environment scenarios into account for overall planning of Rural Roads.

V. CONCLUSION

Surface condition, structure condition, sub-grade condition, material characterization, traffic land use, geometric, environment, economic and operational audits are conducted on different roads coming under maintenance beyond the contractor obligatory period. An interface with multi-criteria evaluation in decision support system is developed to prioritize the roads for sanctioning the maintenance fund over a time and space. Correct quality checks by national and state quality management helps in maintaining the design standards of the roads.

This has proved to be very vital in locating assets of the road and consequent geo tagging which is followed by periodic updates regarding the test, rectification, construction and maintenance. Overall, it has eased and précised the work of the professionals and the core concept of providing ground truth on paper has brought considerable levels of transparency.

The approaches adopted are all different in their own ways and techniques, the software being capable of having diverse course of action on different population and assets. Thus, all the approaches considered can serve equally for the same region or area under consideration by Mean or Standard Approach. Since the all the analysis carried out have no common reference line

to measure the precedence, thus by including the percentile approach a reference line can be generated to set the priority work can be accomplished.

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