Remote sensing and GIS Based Urban Transportation Network Analysis

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Abstract:

The Urban areas are widely spread with more connected road networks. There are many studies shows the impact of urban transportation on economic development of a country. Urban transport provide the mobility of people, goods and access to the public with their amenities, like hospital, education, employment, health, entertainment etc,. Many cities are not providing sufficient road network accessibility in India, these cause transportation problems. In India, many initiatives/polices are taken by Government to address the urban transportation problems. These problems are mainly related to safety, mobility and environment aspects. The implementation of local (state level) initiatives, improve the urban development and connectivity of road network. Since 2006, The National Urban Transportation Policy (UTP) was took a major role in urban road network, which focus on safe and secure transportation. The environmental monitoring and air pollution reduction policies also been prioritized in this initiatives. The implementation of electric vehicles with zero emissions, adopting and developing practice like hot line mobility are taken place. The GOI also implemented metro transportation in urban cities which decreases the traffic congestion. This paper studies transportation policies which are used in urban transportation planning. A part from transportation planning the road or transport accessibility is also important factor in urban studies. The factors influences the accessibility are mentioned in this study. Many studies show the level of urban road network accessibility is studied using Geographical Information System (GIS) software. The GIS integrated with transportation software's like package of GIS-T software and TransCAD software are used to organize the road implementation database, new transport designing and network planning. The Decision Analysis Systems like

MCDA and DSS are implemented in transportation studies to evaluate the alternative road planning. In transportation planning GIS software is a major tool to study the route network and analysis, urban impact assessment and visualization of route map to DSS for transport planning. In this paper the proprietary tools and open source tools of GIS in transportation are explained. This paper concludes that GIS software is a main strength in transportation planning and the initiatives took a major role while planning the new infrastructure of road network.

Key Words: GIS, Open Source, UTP, MCDA, DSS.

1. Introduction

Urbanization, resource constraints and climate change are some of the stress factors that have forced cities to rebuild their urban infrastructure over the 21st century. (Derrible, S., 2017). The development of many urban infrastructure systems is a direct result of the rapid improvement in urbanization. In particular, transport infrastructure plays a key role in ensuring the proper functioning of cities. Transport infrastructure in many cities, new urban travel dynamics and a number of challenges, including traffic congestion and pollution related to transport activities, need to be addressed in order to cope with the evolution of physical infrastructure and infrastructure services that have evolved over time.(Badhrudeen, M. et. al., 2022). Initiation of Smart cities are widely deployed in a suitable manner to address the transportation challenges. Smart city policies aimed at managing challenges in proper method (Pucher J. et. al., 2007). In India the State Transport Undertakings (STUs) established in 1960s and 1970s, this shown a drastically change in the transport system linking cities, towns with villages across the country. Afterwards STUs developed to connect each and every village. In Indian cities the transport demand is increased substantially, as resulted of both natural increase and migration of population from rural to towns (Sanjay Singh K., 2005). Due to this phenomenon the urban population was rapidly increased. In the third year road development plan (1981-2000) of India roads are classified as primary (national and state road), secondary (major district road) and tertiary roads. The tertiary road system, comprising district roads and village roads serves as feeder roads to primary and secondary road system. These territory roads link rural and urban settlements with the nearest centers, shopping complex, markets etc. Some low level roads such as paths and tracks play an

important role in connecting to major roads. These roads not come under the above road classification, but serve a major role in important functions (Ajai Kumar, S, 2010).

Urban road networks are expanding rapidly due to the rapid urbanization worldwide, especially in developing countries (Barthelemy, M., 2015). Urban road network are the skeleton of cities, which provide the accessibility to public with infrastructure.Traffic congestion has become a serious problem in the town and major cities (urban areas). The unauthorized shops, footpath parking, auto rickshaws and personal vehicles block the narrow roads. Flash floods and water logged areas become nuisance on the traffic congestion. Rapid and unplanned urbanization is the main reason for such type of problems. At the same time the extension of the street beyond the limit, lanes and driveways cutting greenery, such type of activities have prolong the problem. Hence, to obtain a traffic free or sustainable road network the analysis of urban transportation planning is essential. A suitable urban transportation system is possible only with the study about the effective performance of road network. The well designed road network improves the accessibility of transportation and decrease the travel time with effective travel cost. The Geographical Information System (GIS) software is a very useful tool to study the transportation system, in realistic and tractable measures. It also identifies the accessibility with respect to space-time. There are many insurmountable weaknesses in the GIS approach to urban transport based on private vehicles, as it is characterized by a number of negative economic, environmental and social impacts.

In this paper, section 2 describes the urban transport initiatives/polices in India. Section 3 reviews the urban transportation planning and accessibility using GIS. Section 4 provides an overview of the GIS software and tools towards transportation. Section 5 concludes with some brief comments.

2. Urban Transportation Initiatives / Policies in India

Transport is a critical component in the Indian economy. Rapidly growing passengers, public vehicles causes issues like traffic congestion, air pollution and fossil fuel consumption. The fast increase in transportation sector show impact on nation Gross domestic product (GDP) (Verma, et.al., 2021). Transportation is also a leading contribution to climate change. To address the transport issues, India initiated some polices towards transportation. There is some policy directions mentioned below:

- To reduce traffic congestion of all transport modes.
- To increase the journeys on foot, by cycle, by two wheelers and by public transport and reduce the use of travelers own four wheelers like cars.
- To reduce the adverse impact of travel.
- To reduce the road accidents and provide safety while traveling
- To reduce the community level influence on the streets.
- To improve the ability of the travelers with low income and educate them about traffic congestion.
- To reduce the growth in congestion and population.

The policies cover different aspects such as Air pollution, bio-fuel, public transport and metro rail improvement, Electric Vehicle establishment distribution to improve transportation standards and reduce road accidents. These policies are implemented in major urban cities throughout India (Thakur et al., 2020).

3.Urban Transportation

Urban roads are defined as Roadways nature, which are characterized by moderate and low speed area, frequent crossing (entrances), and heavy to moderate residential commercial and residential areas. Payment sidewalks, Intersections, unplanned parking, open drainage sections and curbed sections with closed drainage are often characteristic of urban roadways. The Low Speed Urban Street is defined as streets with low posted speeds and variable speed, caused by frequent conflicts. The streets are characterized by a high number of entrances, lots of residential and commercial development. They generally include curb and sidewalk sections, often with building fronts adjacent to or near the back of sidewalk. Frequent intersections, cross walks, and on-street parking are usually present. The road network development influences by the parameters like accessibility, connectivity and spatial pattern, which show a positive and linear relationship with road network. This indicates a strong correlation between these parameters with transportation.

3.1Access Need of Urban Communities

The urban transport is characterized as public transport, private transport and cargo transport. The urban city growth is defined by the transport network system efficiency. Existing road network is not meeting the travel demand in India. The demand can meet with proper connectivity, high

accessibility and effective road network structure. In India, most of the metro cities, the transport network is effectively expanding in the centre, while the peripheral growth is ignored. (Gao, Y. and Zhu, J. 2022). In order to cope with a growing number of people moving in and out of city centres, the transport networks need to be properly planned.Most of the people travel in their own vehicle (car, bike etc.,) which causes traffic congestion at peak hours.

3.2Urban Transportation Planning

It is extremely complex and difficult to evaluate or plan a city's transport system. In order to improve transport in urban areas, it is important to ensure the quality and customer satisfaction. Transport planning is art of designing including the physical infrastructure design with in polices (under boundary of policy). These include railways, roadways, cycle paths and footpaths. The geographical location prioritize is mention while the planning is takes place (eg. community expansion) and long term strategies with a national view. The ability of the transportation structure is affected in long term and short term by various factors, like location, demand, mode and etc. (Gerçek, H. et. al., 2004).The management and operation of useful inputs to decision makers and the provision of a functioning and efficient transport system are the main objectives of urban transport planning. It is important to consider various evaluation factors while ensure the infrastructure investment. The evaluation with different criteria was conducted to do the detailed analysis to identify alternative projects (Jones, S. et.al., 2013). The transportation planning process need to address the transport demand, the increase vehicles population and improved infrastructure of the roads. The stakeholders play an important role in making acceptable public transportation system. Other side there are more specifications like attractive, effective use of urban services and high-quality services for users (Barbosa, S.B, et.al., 2017). The applications such as simulations, lifecycle analysis, environment impact analysis, assessment indicator models, cost benefit analysis optimization and fuzzy set theory are used for transportation evaluation and planning. Among these applications, Multi criteria decision Analysis (MCDA) is mostly used in the transportation network designing and planning. The transportation design complexity and issues in conventional methods are addressed by the MCDA and their hybrid applications. (Browne, D and Ryan, L., 2011). In urban transportation management, public and private transport, network design, Landuse and infrastructure planning are the main typical criteria for this MCDA application. The Multi

Criteria Decision Making (MCDM) method includes evaluate the alternatives, while process the road network design of urban transportation (Hamurcu, M. and Eren, T., 2020).

3.3 GIS in Urban Transportation Planning

Successful transport plans are a combination of spatial and long time strategies of an urban area. Good urban transportation plans depend on robust analysis and modeling of spatial datasets (de Dios Ort'uzar and Willumsen, 2024).In early 1960s planning departments are focused on computer mapping methods, Geographical information System (GIS) was initially developed as mapping software. IMGRID (1977, Simon) was the first mapping grid software developed, and only few mapping organizations installed for their important projects due to cost and limited capacity. In 1980s the fall in price of computers show the increase of utilization of software by many companies is taken place. The use of GIS in different sectors like land use planning, urban planning, transportation, etc., are observed. By improvement of GIS software processing speed many types of advance structures and database development took place (Yeh, A. G.,1999). GIS in transportation include payment management, accident management, traffic management, inventory, signal maintance and transportation network design (Choi, K. and Kim, T. J., 1994). In early 1991 the GIS emerged at a leading tool in transportation studies, the buffer-overlay functions are applied in network studies (Shaw, 1991). ARC/INFO, AML programming and TIGER software are used to demonstrate transport system in both mathematical and graphical representation (Batty and Xie, 1994). The potential benefits of combining transport planning models with geographical information systems are explored in the Choi, K., & Kim, T. J. 1994 paper. They've developed an algorithm based on FORTRAN that will convert topology. This will create transport networks based on GIS cartographic data and establish a communication channel between these two systems. Edward McCormack and Timothy Nyerges (1998) explained the potential inherent in merging technologies of transportation modeling with GIS. The defined functional components for GIS are matched against the list of GIS data modeling within a matrix-based frame work. A sketch network for the region is developed by merging data from a variety of sources using GIS package Trans CAD. Satellite image (Landsat) was used to identify and categorize land use in several alternative corridors for the parkway (Gallimore, W.P. et. al.,1992).

GIS-T (GIS transportation) and Intelligent Transportation System (ITS), focused on sensitive transportation planning which is realistic and tractable. The GIS-T included Space Time Accessibility Measures (STAM). STAMs gives the benefit to the people while estimating the travel time (Miller, H. J. and Wu, Y. H. 2000). Road network designers need Global Positioning System (GPS) to identify the spatial information about location. To link the transit operational data with road network, GPS is integrated with GIS, which demonstrate the Object Oriented GIS. This OO-GIS is useful in several transportation applications (Trepanier, M. and Chapleau, R., 2001). Santhakumar, S. M. et.al., (2003) selected Madurai city to study the effect of the Transportation System Management (TSM) measures with the help of GIS ARC View and Avenue packages. Decision Support System (DSS) is a tool integrated in GIS for planning transportation polices. It involves realistic representation of the multimodal network and implements the solutions to the problems raised against transportation policies (Arampatzis, G. et. al., 2004). Zeng, W. et.al., (2010) designed a data modal which creates routes in real time. This modal generates road layer, route layer and center line separately. Center line generation method is useful in various network analysis studies and improve the route accuracy. Integrated GIS Decision Support System data model develop scenarios in urban areas (like decentralization, concentration area and extensive development) according to transportation system sustainability (Jakimavičius, M., 2009). GIS can play a major role in urban transportation management. To reduce energy consumption the urban sustainable planning of transportation include some smart methods in transportation like i) navigation – which is a basic tool to identify the smallest and suitable route to passengers. Smart intelligent location based GIS provide these services. Collecting and updating the data is required. ii) The second role is safety and road management. iii) Identifying accident prone zones and iv) Perform a perfect land use planning at urban roads adjacent urban areas. (Tao, W., 2013).

The GIS-Based Intelligent Decision Support System (Fig. 1) is used by the road network planners, engineers and urban/municipality decision makers, while taking the decision about new projects of the transportation or road network design planning. (Hasan, M. K. and Al-Qaheri, H. 2013).

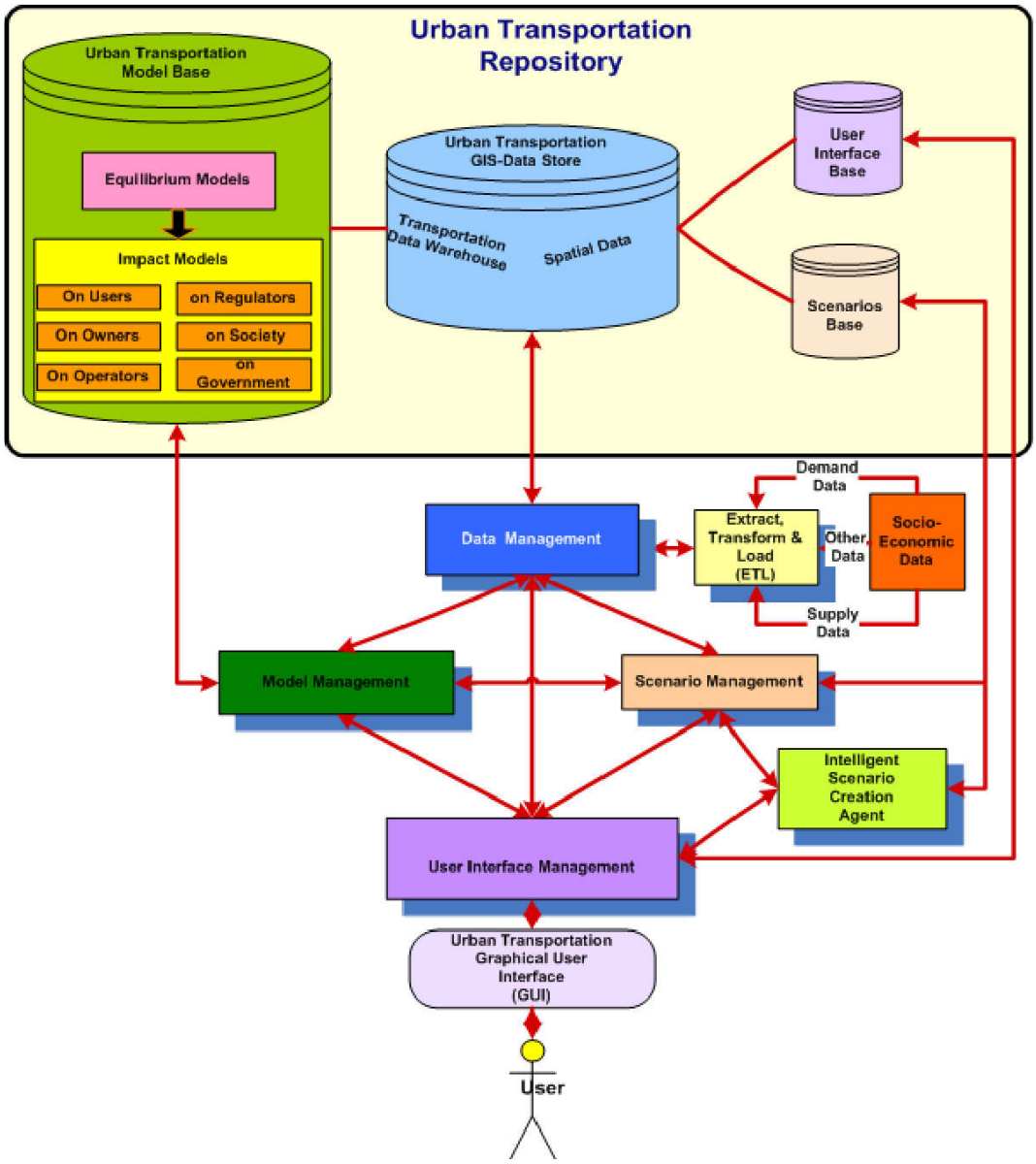

Fig 1. The flow chart of the intelligent DSS for urban transportation systems analysis
(Source: World Academy of Science, Engineering and Technology International Journal of Transport and Vehicle Engineering Vol :7, No:3, 2013).

Transit oriented development (TOD) in corporate land use and transportation to provide a accessibility to transit and local transport in urban area. (Hasibuan, H. S. et.al., 2014). To meet the requirement of future travel demand Asmael, N. M. (2016), conducted the analysis of the existing public transportation using GIS to recommend the necessary optimum transit routes. Suraraksa, J., and Shin, K. S. (2019) proposed a GIS based transportation and distribution network design, which

integrate different scenarios based mathematical models for transport fresh fruits in the Bangkok city. This method was integrate the location, allocation, route analysis, travel time, travel demand etc., like parameters and visualize the best route. To classify the road networks a micro indicator was defined with three GIS layers, such as connectivity accessibility and demand of transport as first indicator. Functionality and performance as second indicator and third indicator is geometry and safety. This integrated system of infrastructure can extract classified urban roads (Gianfranco, F., et. al., 2023). ARC GIS 10.x software provides tools to characterization and visualization of critical road network links in micro, meso and macro perspective. (Yuan, J. et. al., 2023).

3.4 Urban Road Network Accessibility Analysis Using GIS

A variety of factors and researchers have defined accessibility, including the possibility of interaction opportunities (Hansen, W., 1959), the ease with which a land use activity can be reached from a location using a specific transportation system (Dalvi, M. Q., and Martin, K. M., 1976), the autonomy of individuals to choose whether or not to engage in various activities, and the advantages offered by a land use or transportation system (Sahitya, K. S., 2020).One of the most significant effects of the urban transportation system is accessibility. Public transportation is appealing and offers door-to-door mobility in urban areas. According to Yatskiv et al., (2017), the primary goal of the transport accessibility analysis is to improve road network connection for the general public so they can reach their destinations without experiencing traffic jams in metropolitan areas. It is considered as a major factor for quality of life of urban population. Urban transportation accessibility is the product of the planning and assessment of the transit system. Walking, bicycling, and switching from private to public transportation can improve the sustainability of transportation, the local environment, public health, and the economic standing of the populace (Elias and Shiftan, 2012). Social exclusion is caused by inadequate transportation accessibility (Hawas et al., 2016). Thus, one of the primary goals of policy makers and planners in urban regions across the globe is to provide accessible public transportation (Saghapour et al., 2016). There are many influence factors related to public social life impact the transportation accessibility in urban areas. Some of the influence factors are studied by Saif, M. A., et al. (2019), They are studied about the influence factors on public transportation accessibility, such as public health, employment rates, mobility, social exclusion, economical spatial and temporal efficiency.

Different radii are used for each place while computing the various urban services. Weights are allocated to the site according to the significance of the urban service, and weighted scores are then obtained through analysis using the Weight Scoring Model (WSM). The Mean Weight Accessibility Index (MWAI) is measured using these weighted ratings. Using the MWAI, the accessibility level for a location is categorized. According to the MWAI rating, it is described as minimum, moderate, and maximum accessibility. Mobility determines how difficult it is to reach a location using the GIS. In the current world, mobility has become essential (Hernandz, 2017).

4. GIS Open Source Software Tools for Transport Planning

Spreadsheet and specialized transport planning tools are typically used for data pretreatment and analysis stages. Topological (geo referenced) data is provided by GIS, enabling 3D and spatial analysis as well as inquiries like figuring out how far apart two levels of geographic capability are. o locations, the determination of the best path, and the computation of the itinerary (Irizarry and Karan, 2012). Some of the software products which are prominently designed to transportation analysis, designing and planning are mentioned below in table 1.

Software	**Company/HO**	**Availability**	**Benefits in Transportation Planning, and designing**
ArcMap	ESRI/ USA	Propriety	• Effective visualization tools which help in road planning and designing. • network support database to build equitable transportation system. • well designed network analysis tools to study the road connectivity.
Cube	Bentlay/ USA	Propriety	• Multimodal transport and land planning system. • Easily to visualize and compare multiple scenarios. • Reduce rework and errors by using powerful spatial technology tools. • Simple flow charts and to complete tasks quickly.
EMME	Bentlay/ USA	Propriety	• It is a transportation forecasting system used in urban and national wide transport studies. • It include the common appliations like travel demand, forecasting, traffic planning transit planning, pedestrians and bike active transport planning.

			• It allows planners, designers, etc. by modeling the people, places, process and options involved n travel, transport interventions in invention of real world planning decisions.
MATSim	TU Berlin/ Germany	Open Source	• This is a open source frame work for implementing large scale agent based transport simulation.
QGIS	OSGeo/ USA	Open Source	• This is a open source GIS software. • it aids transportation planning by visualization , analyzing and modeling spatial data. • It also provides open street map data. • It identifies the accessibility gaps and congestion hot spot. • It integrates with AI for traffic prediction and offers real time monitoring for public transit. • QGIS also provide different plug-in tools in network analysis.
sDNA	Cardiff/ UK	Open Source	• Works on 2D and 3D model, provide standardizing link node format. • Provide spatial analysis by testing and validating the output with real data. • It show some advantages like allowing wide range data (no data to big data) and visualize the output using DSS tools as full demand modeling • It is a plug-in tool which is used with ArcGIS/QGIS and phython/command line tool in 2D and 3D Auto CAD.
TransCAD	Caliper/ USA	Propriety	• It is a first single integrated platform of GIS software with transportation. • It includes over 2GB of geographic and census demographic data. • It integrates networks, matrices, route related system and linear referencing tools which are most important in transportation planning, designing and infrastructure management.
Visum	PTV/ Germany	Propriety	• It provides multimodal transport modeling in cities. • It is a ideal public transport planning software, which estimate the travel time, frequency and walk time etc. • It enhance operational modeling options with accurate traffic management strategies within local microscopic simulation software PTV Vissim and PTV Optima.

This software tools differs in their priority, well each tool is specialized in one aspect of the transport planning. Decreasing the amount of duplication and reducing the effort to built tools, the identifying and using the best tool from different sources for each project is made compactable. A wide hurdle is between the GIS organization and transport planner is that the functions tend to be spoiled with little communication gap. So the transport planners and may not be access the advance GIS software without a geographic analyst with potential solution to their domain. This relates to siloed into tools. These barriers overcome by using the open source tools integrating in the software to identify the geographic solutions. Open source software gives many advantages then proprietary software. This software can use and download freely, it provide the accessibility of change or modify the source code. The FreeSoftware Foundation (FSF) defined the Open source tools. Open source tools are collectively based on data collection, processing routing, modeling and visualization. The classification of open source tools are based on user interface (UI), to identify them on web search are mentioned below.

- Graphical User Interface (GUI) tools
- Command-line Interface (CLI) tools
- Web User Interface (WUI) tools and
- Application Programming Interfaces (API) keys.

Numerous software projects, spanning various programming languages, exist, with many of them no longer receiving active maintenance (Coelho et al. 2020). To discover open source tools for transportation planning, diverse search engines and code hosting platforms were employed, utilizing relevant keywords.Verified these open source tools participation (active or not) via citations and stars, verified the source code by checking with available license (Lovelace, 2021). Command Line Interface (CLI) tools for geographic analysis in transportation are first realized in 2001 by SUMO software (Lopez, P.A., et al, 2018). Most of the Graphical User Interface (GUI) tools are provide by QGIS software as plug-in (Camargo, P., 2015). sDNA provide GUI tools to analyze the spatial network in transportation planning, cycling and walking(Cooper, C. H., & and Chiaradia, A. J, 2020). In Web User Interface (WUI), GUI is widely used an in browser user interface which can used in transport planning. These tools are developed in a social context with encouraging solutions. These open source tools are mutually supportive and collaborative in nature (Dhir and Dhir 2017).

5.Conclusions

This review paper summarizes the GIS based transportation planning, accessibility and transportation initiatives taken Government of India for urban transportation. As well as the GIS open source and proprietary software used in transportation system also mentioned. The GIS based MCDA came used by planners, designers in transportation studies. The DSS is a useful tool in transportation designing, which helps engineers and urban municipalities while implementing a new transport (road infrastructure) development project. Urban transport is a combination of multiple polices and operations. These policies are implemented by GOI to address the transportation problems. A significant implementation in urban transportation was initiated in 2006 by National urban transportation policy. The JNNURM, NUTP and NMT policies provide the drastic improvement in urban transportation development. The electricity vehicles are introduced to reduce the emission and improve air quality. Urban transport is more attractive with the road accessibility. The accessibility of urban transportation is measured by using GIS techniques was found in many studies. The performance of the road accessibility was identified using GIS tools. GIS software is an essential programming tool for transportation management and planning, offering a wide range of benefits and applications. The wide use of proprietary tools and open source tools of GIS in transportation is observed in many studies. This study shows that the softwares like R, Python and QGIS communities have already developed many open source tools which are useful in transportation studies. The combination of these tools opens the solutions for a wide range of spatial transport planning problems. This paper therefore concludes that the integration of GIS with transportation planning provides solution transportation problems. The open source tools for geographic analysis are widely used in transport planning can support emerging environmental, health and social objectives

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