



Research Article



Road network analysis of Guwahati city using GIS

Debashis Das¹ · Anil Kr. Ojha¹ · Harlin Kramsapi¹ · Partha P. Baruah¹ · Mrinal Kr. Dutta¹

© Springer Nature Switzerland AG 2019

Abstract

Starting from the past or medieval period to the present day situation, history clearly indicates that the development of a region was and even today is function of a good transportation network. In the present day, society demands for an efficient and unobstructed road network after experiencing major issues or problems like traffic congestion, delay, pollution, increased vehicle operating cost and road accidents. Keeping in mind the above needs and constraints to traffic movement, an analysis of a digitized road network of the concerned city/town can be one of the best remedy to solve the problems. Such analysis is best suited in ArcGIS, Geographic Information System (GIS) software for creating, analyzing and compiling maps for obtaining information. In the present study an effort was made to prepare a road network map of Guwahati city and to find the shortest route between two places by proper analysis and digitization of its existing road network system in order to solve the traffic related problems to great extent. Network Analyst is a special analysis tool in ArcGIS which not only scrutinize the closest facility available in network of digitized interconnected lines but also facilitates in optimizing route during floods and emergency responses. One of the best models that can be generated through Network Analysis is the shortest route between required origin and destination points. The analysis is done based on input of certain network attributes like traversing distance, time and cost of travel, barriers, vehicle restrictions etc. All the important roads connecting each other within the Guwahati City were digitized in the GIS environment and proceeded further to serve the purpose.

Keywords ArcGIS · Digitization of maps · Road network · Network analysis · Shortest route

1 Introduction

The Indian highway network (IHN) is one of the busiest road networks in the world, constituting 2% of all roads in India but handling 40% of the total road traffic as of 2010 [1]. Traffic congestion occurs in certain parts and stretches of roads in Guwahati. Inadequate parking space, exorbitant bus, auto rickshaw, rickshaw and taxi fares, time-consuming and uncomfortable journey, frequent accidents are the causes and consequences related to traffic in the city. Flood inundation and water-logging problems are also faced in several ward of Guwahati Municipal Corporation area during the rainy season. Rapid urbanization with

increased housing more rooftops, driveways, streets and other impervious or hard surfaces [2]. Hence to overcome the problems and to keep up sustainability, proper analysis of the present road network is very much crucial to help humanity to reach their destination with ease, reduced cost and time etc.

A GIS is an organized collection of computer hardware, software, geographic data, and personnel to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information. ArcGIS Network Analyst enables users to dynamically model realistic network conditions, including turn restrictions, speed limits, height restrictions, and

✉ Debasish Das, debashisdas2020@gmail.com | ¹Department of Civil Engineering, Jorhat Engineering College, Jorhat, Assam 785007, India.



SN Applied Sciences (2019) 1:906 | <https://doi.org/10.1007/s42452-019-0907-4>

Received: 17 February 2019 / Accepted: 10 July 2019 / Published online: 23 July 2019

traffic conditions, at different times of the day [3]. ArcGIS proved to be one of the most user friendly, effective and time-saving tools in the field of both traffic engineering and transportation planning.

2 Methodology

For the network analysis of Guwahati City, a street basemap was added in ArcGIS software from the Google Earth satellite imagery and geo-referenced to get the co-ordinates. Geo-referencing involves image alignment in a co-ordinate system [4]. The study area is being enlarged to an easily workable scale as shown (Fig. 1).

Layers are the mechanisms used to display geographic datasets in ArcGIS. For the analysis, the layers were being categorized as major road (mainly the Highways) and minor road (city roads connecting the highways and other urban localities), lanes and by-lanes in addition to wards. The table of contents lists all the layers on the map and shows what the features in each layer represent [5]. After successful creation, the base map digitization for each layer was done to form a skeleton of the prevailing road network. Digitization is process of making an electronic version of a real world object or event, enabling the object to be stored, displayed and manipulated on a computer, and disseminated over networks [6]. The entire GMC area is divided into 31 municipal wards and each municipal ward is further divided into 2, 3 or 4 Area Sabhas (subwards). A

ward map was drawn as a layer over the Guwahati city based on the official GMC (Guwahati Municipal Corporation) map (Figs. 2, 3).

3 Analysis

Network analysis in GIS rests firmly on the theoretical foundation of the mathematical sub disciplines of graph theory and topology. The most common and familiar implementations of network models are those used to represent the networks with which much of the population interacts every day: transportation and communications networks [7]. Routing is the act of selecting a course of travel, and it is arguably the most fundamental logistical operation in network analysis. Although network analysis in GIS has been largely limited to the simplest routing functions, the recent past has seen the development of object oriented data structures, the introduction of dynamic networks [8], the ability to generate multi-modal networks, and the use of simulation methods to generate solutions to network problems. There are, of course, many important network design problems that are very difficult to solve optimally due to their combinatorial complexity [9]. To allocate and provide urban facilities in an area with complex road network, determination of the shortest route as well as travel demand (trips generated and attracted) from the facility to the concerned area is a must. Generating the shortest path between two locations in a road network is a problem that can be solved by various map services and commercial navigation products [10]. There are several extremely efficient algorithms for determining the optimal route, the most widely cited of which was developed by Edsger Dijkstra (in the year 1959).

The algorithm [11] is represented in brief as below:

$$G = (V, E)$$

where **V** is a set of vertices and **E** is a set of edges.

Dijkstra's algorithm keeps two sets of vertices:

S the set of vertices whose shortest paths from the source have already been determined.

V-S the remaining vertices.

The other data structures needed are:

D array of best estimates of shortest path to each vertex

Pi an array of predecessors for each vertex

The basic mode of operation is:

1. Initial is **d** and **pi**.
2. Set **S** to empty.
3. While there are still vertices in **V-S**.

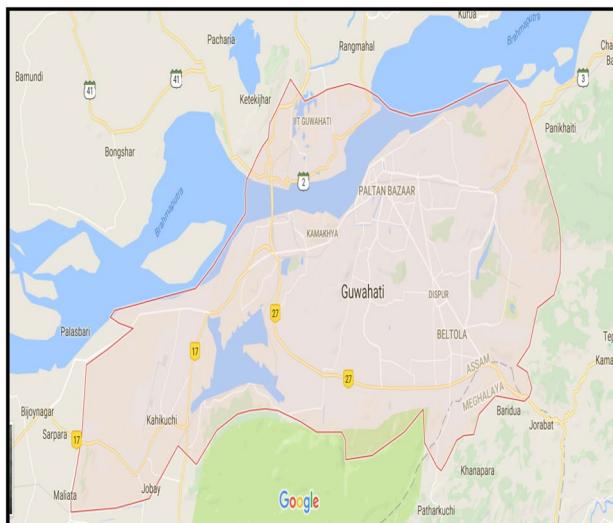


Fig. 1 Image showing the enlarged study area (Guwahati city) marked as red color (Google Maps 2018)

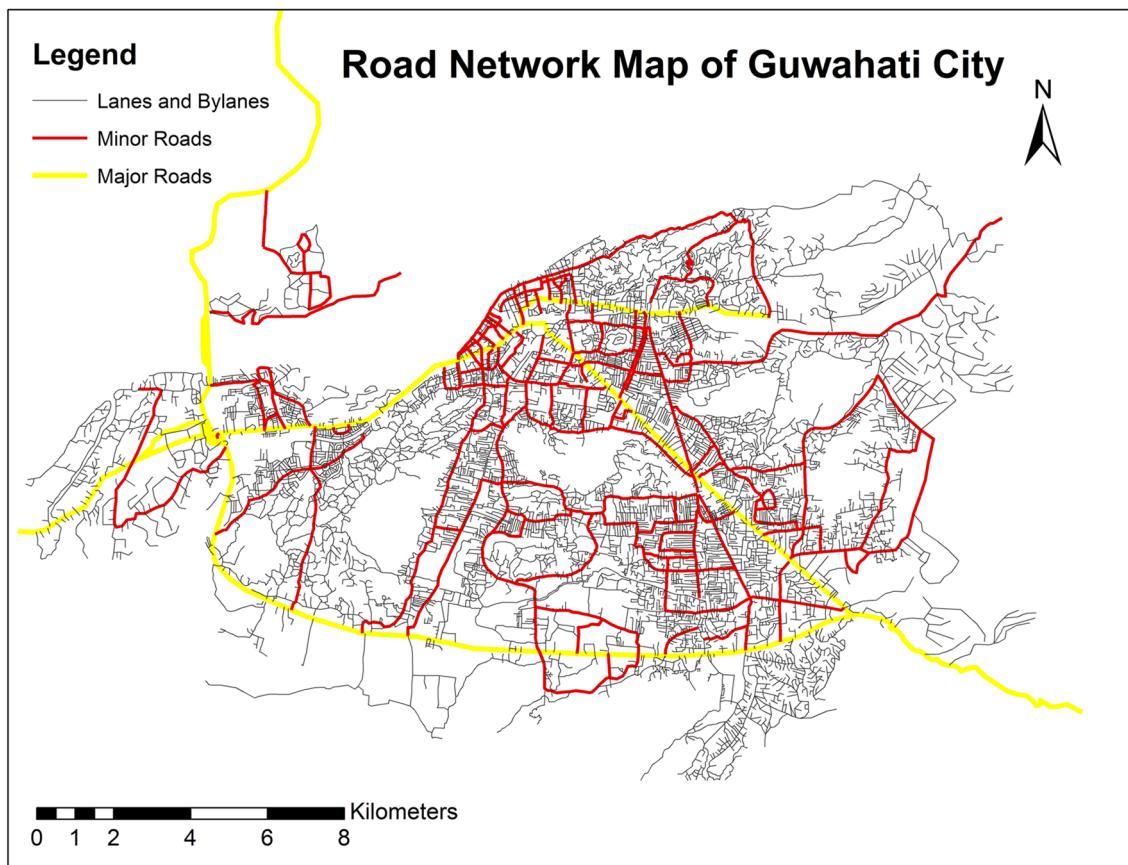


Fig. 2 Road network map of Guwahati city drawn in ArcGIS software

- Sort the vertices in $V-S$ according to the current best estimate of their distance from the source.
- Add u , the closest vertex in $V-S$, to S .
- Relax all the vertices still in $V-S$ connected to u .

Pseudo code for Dijkstra's Algorithm:

```

Distance [s] ← 0 (distance to source vertex is zero)
for all v ∈ V-{s}
do distance [v] ← ∞ (set all other distances to infinity)
S ← ∅ (S, the set of visited vertices is initially empty)
Q ← V (Q, the queue initially contains all vertices)
while Q ≠ ∅ (while the queue is not empty)
do u ← min distance (Q, distance) (select the element
of Q with the min. distance)
S ← S U {u} (add u to list of visited vertices) for all
v ∈ neighbors[u]
do if distance [v] > distance [u] + w(u, v) (if new shortest
path found)
then d[v] ← d[u] + w (u, v) (set new value of shortest
path)
(if desired, add trace back code)
return dist.

```

To run the analysis over the digitized road network, a network geo dataset was created which resulted in a layer consisting of the junctions and edges connected topologically to each other. Ward analysis was done using Intersection tool to get the statistics of all the categorized roads created as layers. The origin and destination points were selected to solve the network for determination of the shortest route and to serve the purpose of our study (Fig. 4).

An attribute table, tabular arrangement of meaningful data, of the digitized road network was generated to get the latitudes and longitudes (in degrees), road ID and name and the distances (in meters) between the junctions (or origin to destination) (Fig. 5, Table 1).

4 Results and Discussions

The results can be interpreted as follows:

Guwahati city has been divided into 31 main municipal wards which are further subdivided forming a total

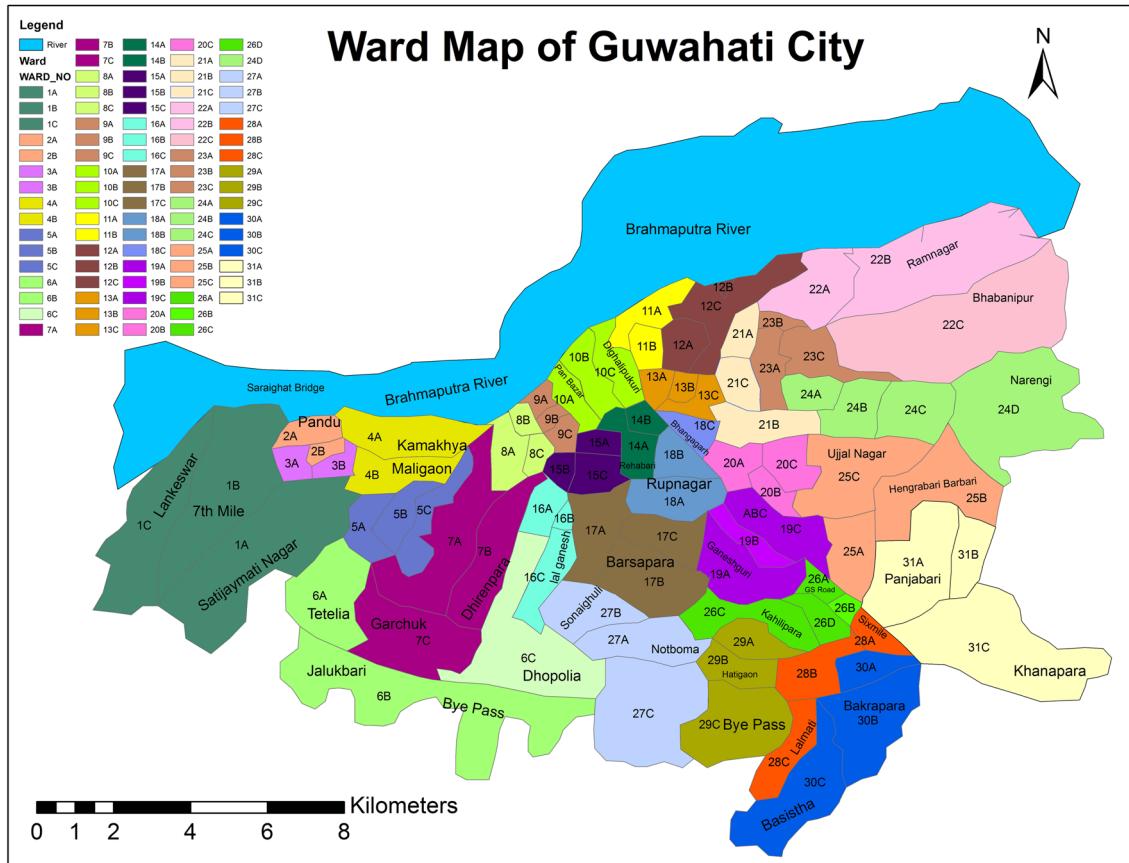


Fig. 3 Ward map of Guwahati city

of 90 wards. From the ward-road network analysis, it has been seen that-

- A. Ward 22C has the largest area (9.954 km^2) and Ward 12B has smallest area (0.103 km^2). The 3 major roads pass through the 44 wards of Guwahati city out of which the ward 1B covers the maximum number of major roads (2) with a total length of 7.873 km . 48.88% of the wards have the major roads (Figs. 6, 7).
- B. All the minor roads pass through 85 wards of the city out of which the ward 10A holds the maximum number of minor roads (9) with a total length of 4.554 km . The lanes and by-lanes cover up all the wards among which ward 6C has highest number of lanes (148) traversing throughout with a total length of 37.305 km . 94.44% of the wards have the minor roads.
- C. Lanes cover up all the wards.

But when it comes to existing road density or the number of specific roads in all the wards, more than the half of the total wards (90 wards) doesn't have sufficient roads. Such deficiency of road networks is mostly seen in the outer areas cum rural urban of the city including the rural villages. Limited roads and poor network is one of the reasons for traffic congestion. Traffic congestion leads to delay of vehicles, increased vehicle operating cost, increase in air and sound pollution, emission of poisonous gases like Carbon Monoxide (CO), road accidents, warming up of surrounding urban area, human frustration leading to road rage etc. From the field survey, it has been observed that for feeder trips, both transit and Para transit use some other routes other than the shortest route as per GIS. The reasons are numerous like transport movement policy, poor pavement conditions, unawareness of non-commuters etc. (Fig. 8).

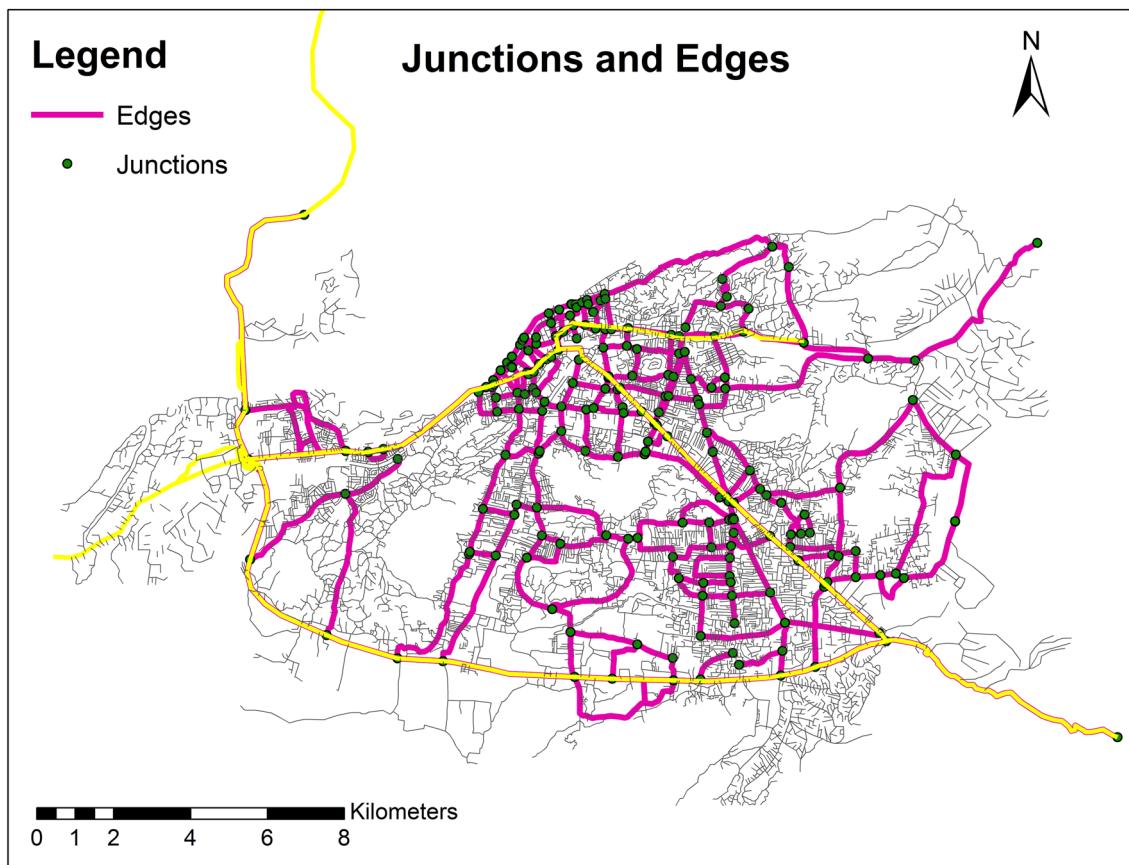


Fig. 4 Junctions and edges of the digitized road network generated by network analyst toolbar in ArcGIS

Minor_Road					
OBJECTID*	SHAPE *	SHAPE_Length	NAME_OF_THE_ROAD	Latitude_1	Longitude
2	Polyline	1124.88204	Haj S Road	91.744124	26.179197
3	Polyline	776.066607	Phukan Road	91.749163	26.173694
4	Polyline	799.074371	BK Kakoti Road	91.754018	26.168438
5	Polyline	776.491981	Banga Kanta Road	91.748453	26.168766
6	Polyline	1196.068128	Hale Baba Road	91.754018	26.168438
7	Polyline	807.619152	SJ Road	91.740077	26.176021
8	Polyline	421.019169	Sudhas Road	91.742538	26.16975
9	Polyline	2291.918253	GMC Hospital Road	91.748453	26.163583
11	Polyline	1627.140023	Ashram Road	91.754777	26.174005
13	Polyline	852.176765	Fayal Ahmed Road	91.741167	26.159941
15	Polyline	7167.398651	Kahlipara Road	91.740732	26.147581
17	Polyline	6121.214678	AK Deb Road	91.733411	26.158611
18	Polyline	4042.374692	Zoo Road	91.775338	26.180241
19	Polyline	4973.519704	Basistha Road	91.788794	26.145085
21	Polyline	7373.33832	Pangbari Road	91.80809	26.131599
23	Polyline	5318.598704	VP Road	91.828673	26.17013
24	Polyline	5888.698848	Geetanagar Road	91.776767	26.174527
25	Polyline	8241.857799	GN Bandoboi Road	91.740615	26.181912
27	Polyline	4967.122191	Lohra Road	91.740732	26.147581
28	Polyline	1760.507708	Rehabari Road	91.75057	26.178564
30	Polyline	756.191737	AK Azad Road	91.748453	26.163583
33	Polyline	1331.756768	Netra Subhash Chandra Bose Road	91.741167	26.159941
37	Polyline	498.526918	Iabhatia Road	91.736003	26.148194
38	Polyline	4173.115069	Savukuchi Tinal Hockey Stadium Road	91.736003	26.148194
39	Polyline	3194.384907	Dakhangon Road	91.744344	26.126203
40	Polyline	751.830397	“Nul”	91.80809	26.131599
41	Polyline	1922.314018	Japorgog road	91.780532	26.163292
42	Polyline	844.381101	Nayanpur road	91.785083	26.149864
43	Polyline	2757.194104	Khagen Mahanta Path	91.788784	26.14857
44	Polyline	407.477954	Puberun Path	91.794469	26.150191

Fig. 5 Image showing the attribute table of the digitized road network of Guwahati city

Table 1 Statistics obtained on performing ward analysis

S. no.	Description	Results
1	Total no. of major roads	3
2	Total no. of minor roads	135
3	Total no. of lanes and by-lanes	4476
4	Total length of major roads (in km)	75.971
5	Total length of minor roads (in km)	919.499
6	Total length of lanes and by-lanes (in km)	1298.834

A network analysis layer stores the inputs, properties, results of a network analysis and is always performed on network dataset. Network analysis in GIS rests firmly on the theoretical foundation of the mathematical sub disciplines of graph theory and topology. This paper is presented taking into account the route analysis layer

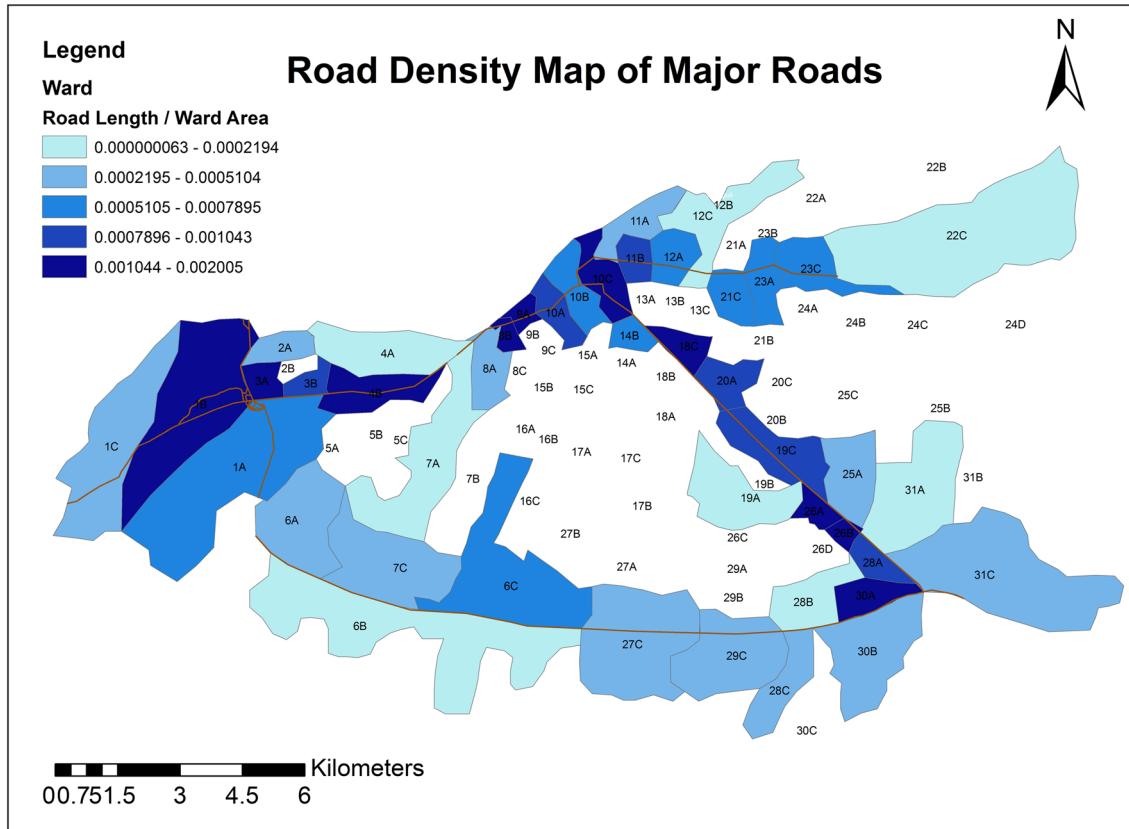


Fig. 6 Map showing density of major roads ward wise in ArcGIS

and the analysis is based on real time network problems independent of the hierarchy (major roads, minor roads and lanes). **GIS networks consist of interconnected lines (known as edges) and intersections (known as junctions) that represent routes upon which people, goods, etc., can travel.** Network analysis helps in modeling as well as planning and management of moderate to heavy traffic routes. One common type of network analysis is finding the shortest path between two points. Junctions (or nodes) and edges have certain attributes affixed to them which help in modeling. Edges and junctions are topologically connected to each other—edges must connect to other edges at junctions, and the flow from edges in the network is transferred to other edges through junctions.

Determination of the shortest route between the origin and destination using the GIS Network Analyst will not only help the tourists or business entrepreneurs to

access the tourist places or the trade centers with ease but it will also reduce cost and avoid traffic congestion resulting in less emission of pollutants. **Dijkstra (1959) proposed a graph search algorithm that can be used to solve the single-source shortest path problem for any graph that has a non-negative edge path cost [12].** Network attributes are properties of the network elements that control movement over the network and helps in finding the shortest route based on type of attribute such as distance, vehicle restrictions, turn restrictions etc. **This paper presents the shortest route based on the assumptions that traffic congestions are not considered and the calculations are based on road distances (Figs. 9, 10; Table 2).**

D. To travel from Nepali Mandir, Paltan Bazar to the ISBT, Guwahati there are three relatively shorter routes, the distance and via of which are given below:

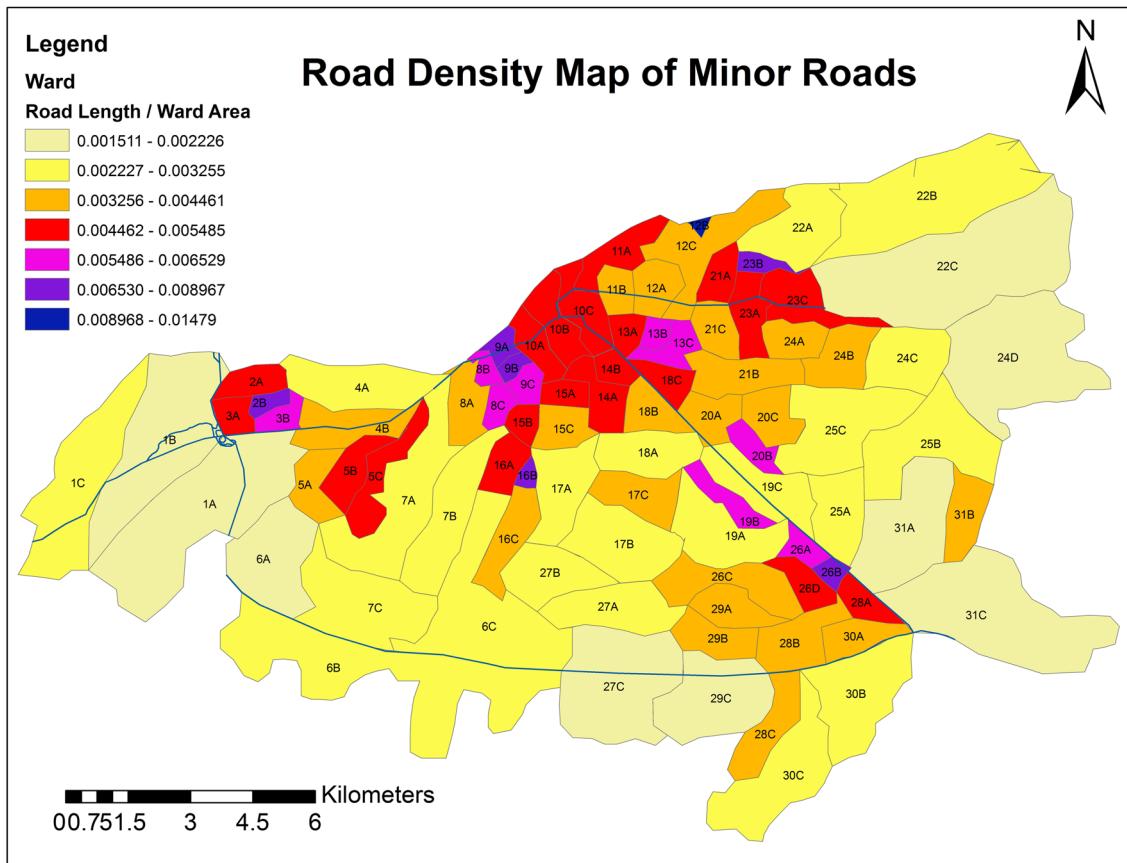


Fig. 7 Map showing density of minor roads ward wise in ArcGIS

- via Lal Ganesh, Distance = 12 km
- via Faye Ahmed Road, Distance = 9.3 km
- via Dhirenpara Road, Distance = 8.9 km

Division of the different types of vehicular road traffic into alternative shortest routes on the basis of operating characteristics and mileage performance of vehicles and proper revision of the transportation policy of the concerned can tackle the traffic congestion.

5 Conclusion

Thus Network Analysis is one of the most powerful tools to deal with the real time transportation problems. It is reliable, user friendly and efficiently solves the network problems. It has replaced the conventional methods of

analyzing and saves lot of time and work. It emerged out as the helping hand in the field of transportation planning, origin and destination studies. It has high potentiality in analyzing the closest facility and service areas in a network. Ward analysis is another easiest way to know the present density and number of roads in service which in turn would help in transportation planning keeping in consideration the various aspects. Information about the shortest route would help the drivers and road users to save the transportation cost, time and avoid traffic congestions in commuter routes by diverting the excess flow through less travelled shorter routes. Road structure improvement of the shortest routes by widening and imposing restrictions to parking would be a beneficial factor. Signal timing should be adequate for the intersecting shortest routes to serve maximum flow and avoid delay. Law enforcement should be strictly

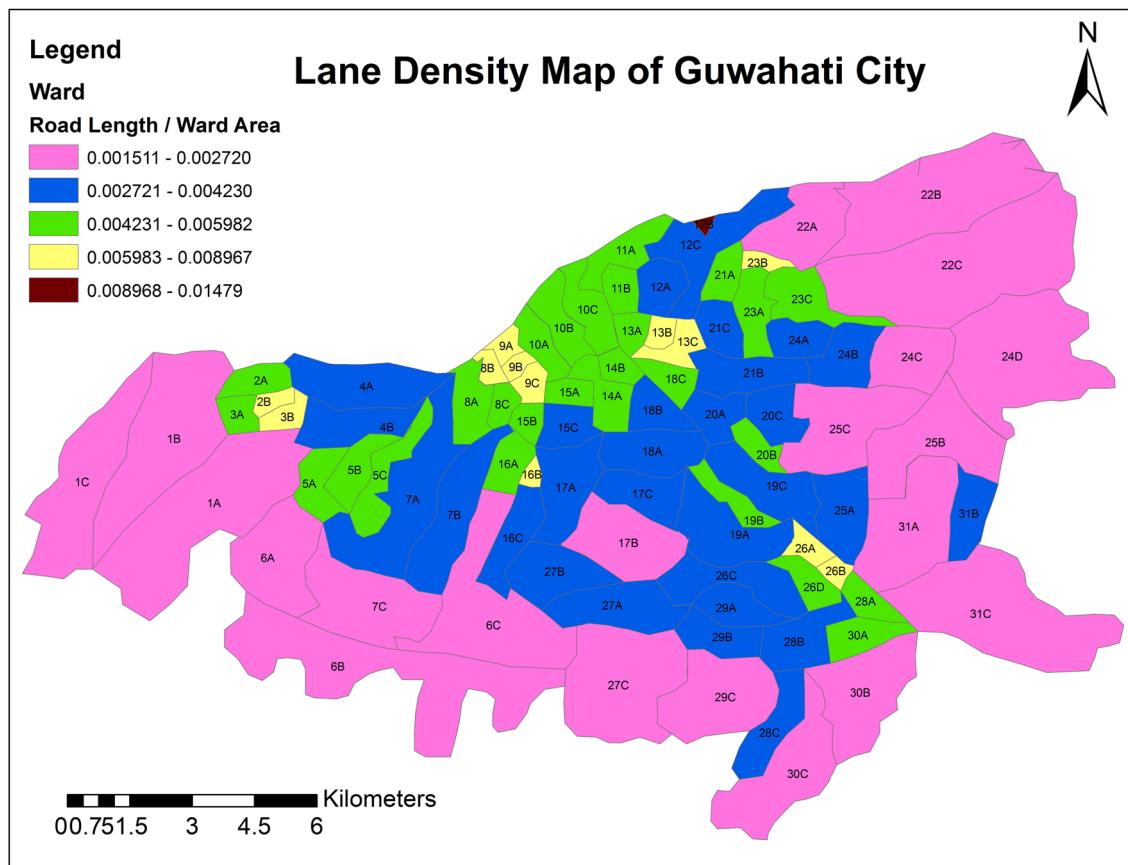


Fig. 8 Map showing density of lanes and by-lanes ward wise

implemented on such routes to maintain discipline and stimulate the urban development. Increasing the number of minor roads (provided those are shortest) in wards concerned depending on the demand for transportation to-

1. Avoid congestion in the existing single routes.
2. Increase connectivity of the rural urban with the major road to avoid entry into the Central Business District (CBD).

As a whole, it can also be concluded that GIS has a lot of applications directly or indirectly in the field of transportation as the studies about the existing road network problems as their solutions can enhance the economy of a locality to a great extent. Implementation of the advanced technologies can be beneficial to maintain the sustainability and transportation related GIS tasks should be preferred for better output in future.

6 Research and Development (R&D)

The work has been carried out considering distance as impedance. In many cases, it has been seen that, the shortest route in terms of distance doesn't always mean the shortest one in terms of time. One of the prime reasons is the huge flow of vehicles through the only shortest route leading to time consumption. Further work with much improved accuracy and efficiency should be carried out considering time as impedance factor. Traffic Data in real time for different routes has to be obtained from Google maps. Google Maps Traffic uses GPS signal data from smartphones in order to sustain such an immense algorithm [13]. It calculates the speed of the users which helps in knowing the affected routes. The shortest route algorithm can preserve the travel time with 20–22%, depending on the travel distances [14]. Although finding the shortest route between two points might be a known case for the mass using the Google Maps, but it gives long range transportation planning

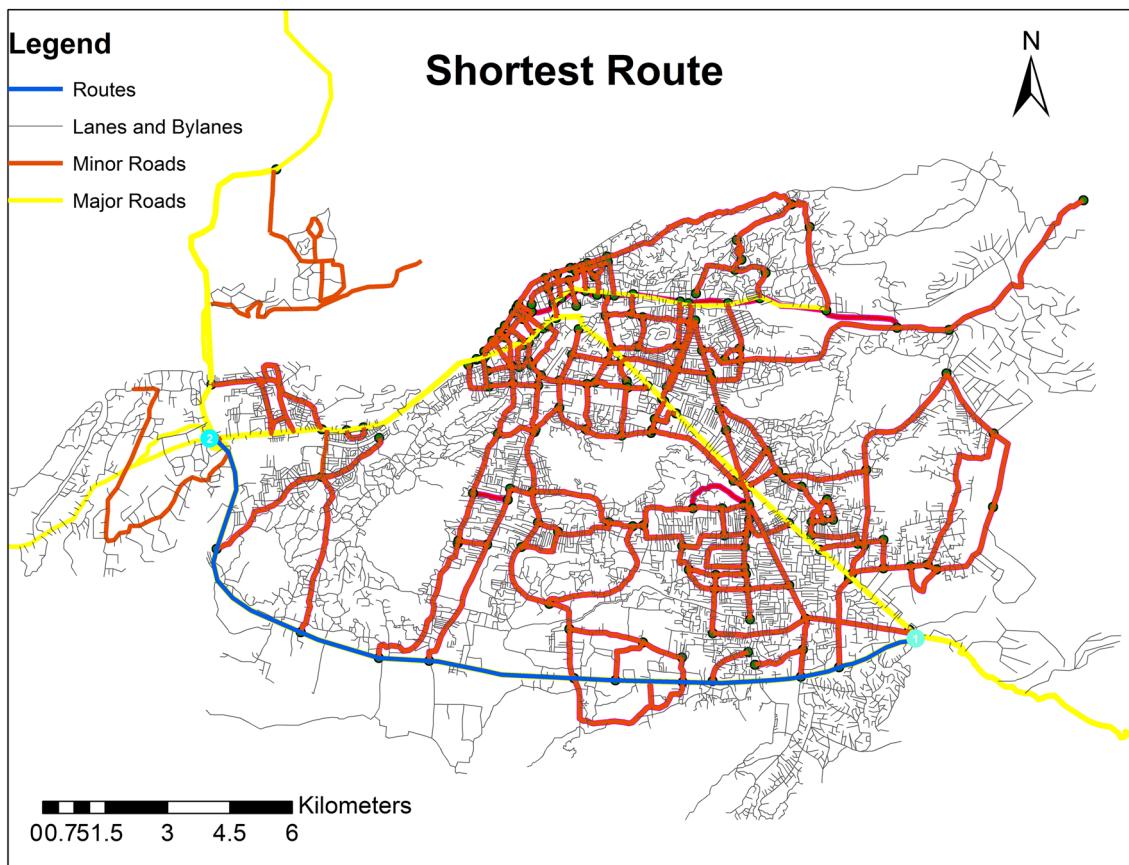


Fig. 9 Image showing the shortest route between Khanapara old ASTC point to Jalukbari flyover point (shown by blue color) in ArcGIS

solutions like determining the zones/areas where urban activities like shopping malls, schools/colleges, offices, industries, health centers, recreational centers etc., has to be established at a specific location depending on the travel demand and the availability of required class of roads to make accessible to the people within as well as outside the locality. Since there are many places around the globe where internet/mobile connectivity is either less or nil, the shortest route map becomes

the replacement of Google Maps. In addition to that, research work can be carried out to determine the path for establishing higher modes of public transport like Light Rail Transit (LRT), Metro trains, Bus Rapid Transit (BRT) etc. Also, the choice of shortest route due to variation in traffic during different times of the day, seasons, climate, festivals etc., and during emergency situations like accidents, fire etc., can be studied.

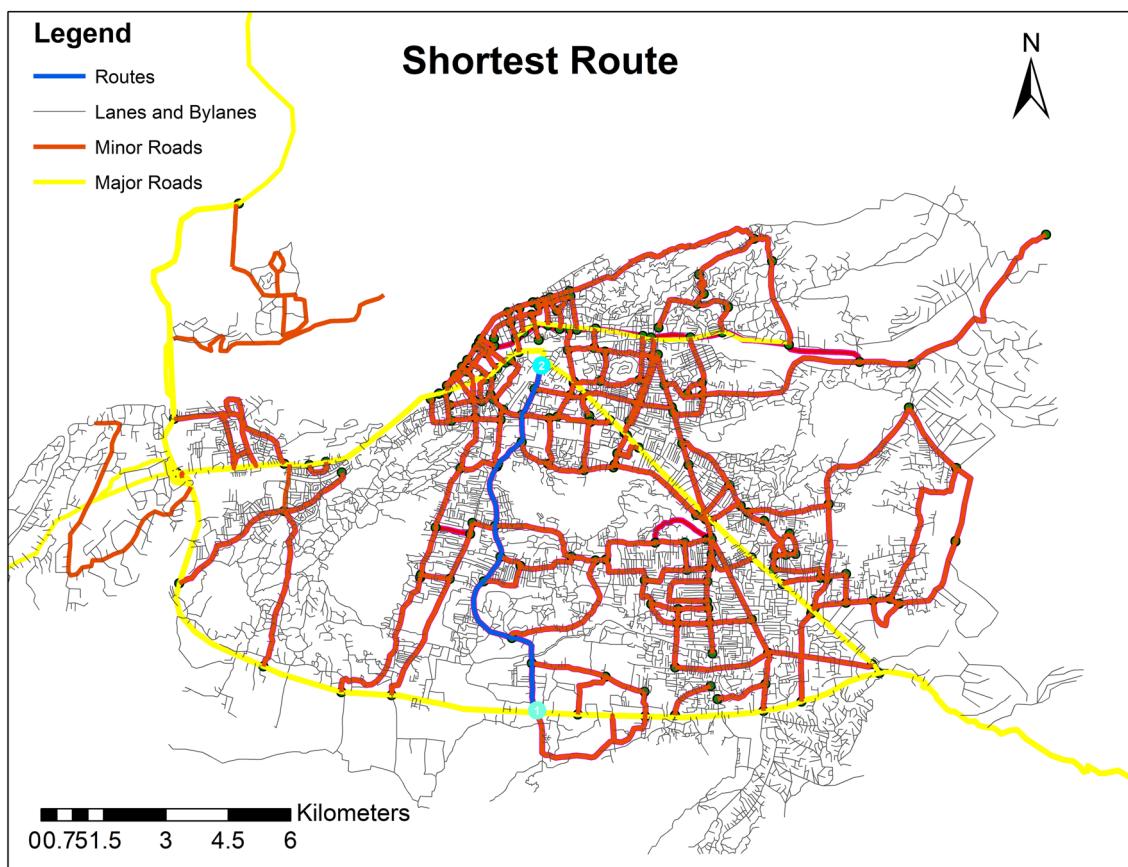


Fig. 10 Image showing the shortest route between Paltan Bazar to Lokhra Bamunpara Chowk (shown by blue color) in ArcGIS

Table 2 Shortest distance measurements

To traverse		Shortest route is via	Total distance (km)
From	To		
Khanapara old ASTC point	Jalukbari flyover point	Guwahati Bypass, NH 37	18.779
Paltan Bazar	Lokhra Bamunpara Chowk	Lokhra Road	8.775

Compliance with ethical standards

Conflict of interest On behalf of all the authors, the corresponding author states that there is no conflict of interest.

References

- Mukherjee S (2012) Statistical analysis of the road network of India. *Pranama J Phys* 1:2. <https://doi.org/10.1007/s12043-012-0336-z>
- Barman P, Goswami DC (2009) Floodzone of Guwahati municipal corporation area using GIS technology. In: 10th ESRI India user conference 2009
- Kumar P, Kumar D (2016) Network analysis using GIS techniques: a case of Chandigarh city. *Int J Sci Res (IJSR)* 5(2):409–411
- Herbei MH, Ciocla V, Smuleac A, Nistor E, Ciocla L (2010) Georeferencing of topographical maps using the software ArcGIS. *Res J Agric Sci* 42(3):595–606
- Laixing L, Deren L, Zhenfeng S (2008) Research on geospatial information sharing platform based on ArcGIS server. In: The International archives of the photogrammetry, remote sensing and spatial information sciences, vol 37, Part B4, pp 791–795
- Manjula KR, Jyothi S, Varma AK (2010) Digitizing the forest resource map using ArcGIS. *IJCSI Int J Comput Sci Issues* 7:300
- Kurtin KM (2007) Network analysis in geographic information science: review, assessment and projections. *Cartogr Geogr Inf Sci* 34(2):103–111
- Sutton JC, Wyman MM (2000) Dynamic location: an iconic model to synchronize temporal and spatial transportation data. *Transp Res Part C Emerg Technol* 8(1–6):37–52
- Magnanti TL, Wong RT (1984) Network design and transportation planning: models and algorithms. *Transp Sci* 18(1):1–55
- Lingkun W, Xiaokui X, Dingxiong D, Gao C, Andy DZ, Shuigeng Z (2012) Shortest path and distance queries on road networks: an experimental evaluation. *VLDB* 5(5):406–417
- Khaing O, Wai H, Myat E (2018) Using Dijkstra's algorithm for public transportation system in yangon based on GIS. *Int J Sci Eng Appl* 7(11):442–447

12. Akpofure ON, Paul AN (2017) Anapplication of Dijkstra's Algorithm to shortest route problem. IOSR J Math (IOSR-JM). e-ISSN: 2278-5728
13. Hajnalka KA (2018). Road network analysis using GIS techniques in the interest of finding the optimal routes for emergency situations. Case study: CLUJ-NAPOCA (ROMANIA), Geographia Napocensis Anul XII, nr. 1, 2018
14. Ahmed S, Ibrahim RF, Hefny HA (2017) GIS based Network Analysis for the Roads Network of the Greater Cairo Area. In:

Proceedings of the international conference on applied research in computer science and engineering ICAR'17, vol 2144, no 1 at <http://ceur-ws.org>

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.