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RESEARCH ARTICLE

GIS-Based Assessment of Best Route in Complex Traffic Environment: A Case of Kolkata Municipal Corporation

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Abstract. In an emergency like an urban fire, road accident, or critical condition of patients, the shortest possible route to reach the destination is one of the most sought-after issues in transportation studies. However, the physical distance of the shortest route becomes longer distance than the travel time distance due to traffic congestion in metropolitan cities like that of Kolkata. So, the selection of an alternative route is essential to organize the journey logically. A well-structured road network provides multiple options to road users for selection of the best route from the shortest and alternative route according to their demand. So, the present study aims to identify the structural characteristics of road networks by graph theory and the selection of the best route using the GIS technique. It has been found that the road network of Kolkata is characterized by complex structure and grid configuration of the network. Selection of the best route also ranges from the shortest route to alternative route due to spatial variation of traffic speed on different roads in peak hours. The current study identifies the optimal route in terms of travel time to reach the required destinations during peak hour duration in the city of Kolkata.

1. Introduction

Kolkata has been facing various problems related to the traffic environment like extreme traffic congestion (Chakrabartty & Gupta, 2015; Chowdhury, 2015), road accidents (Ray & Bhaduri, 2018; Mukherjee & Mitra, 2020) and urban fire (Ghosh & Mondal, 2019; Purkait & Halder, 2016). There are many factors like road traffic, narrow streets, accidents, infrastructure conditions, one-way roads, crosswalks, stops, etc. which influence urban circulation (Ivan et al., 2015). Road design and capacity have a very important role in controlling these types of urban hazards because the road network connects the road accident spots and fire spots with facilities like hospitals, fire stations, police stations, etc. Identification of shortest routes, alternative routes, and best routes with their widths between fire-prone areas and fire stations in peak hour situations is very important for quick rescue operations because here time is the crucial factor in controlling the effect of fire (Ghosh & Mondal, 2019). So, the time gap between a fire event and a fire rescue operation is dependent on the speed of the fire vehicle or engine. Further, an ambulance should reach the hospital at the right time to save the patient's life, especially in accident events (Shivaprasad et al., 2018). One hour after the accident is the golden hour for the treatment of accident victims, so, an injured person should be moved to the hospital very fast. Moreover, travel time is also very important for daily travel, particularly to the workplace. Number of studies have determined the level of service of roads (Biswas et al., 2016; Das & Ahmed, 2018) in Kolkata and suggested various measures to control traffic congestion and reduce travel time by improving the efficiency of road networks (Arti et al., 2022; Chu & Thi, 2017; Toulni et al., 2023). Therefore, an efficient road network is essential for emergency vehicles as well as public and private cars. Structural analysis of transport networks is essential to measure the efficiency of road networks (Cole & King, 1968) and is also required to represent certain spatial issues of the socio-economic system (FitzGerald, 1974). Graph theory (Sadavare & Kulkarni, 2012) and GIS tools (Rai et al., 2013) are important approaches to road network analysis. In this paper connectivity and accessibility have been measured as a part of the structural analysis of the network through graph theory and the GIS tool has been used to evaluate the efficiency of the road network in the perspective of traffic congestion in Kolkata. Route choice behavior among travelers from the logical point of view has been assessed using the best route tool in GIS software. The main objective of the present study is to create an elaborate and more complex methodology to identify the optimal routes for emergency situations and identify the best route based on time during peak hours in Kolkata Municipal Corporation.

2. Study Area

The study area is the Kolkata Municipal Corporation area (22°30' N to 22°37' N latitude and 88° 23' E to 88°18' E longitude) which has a total road length of 4,636 km (Ray, 2018). A total 17, 46,838 registered motor vehicles (Kolkata Traffic Police, 2018) and 187 – 322 lakhs daily transit passengers (KMDA, 2008) have used the road infrastructure of the city. Major travel directions and demands have been organized based on several urban facilities like health, administration, opportunities of transport modes, business etc. Total fourteen major traffic points viz. Garia, Science City More, Sinthir More, Shyambazar five points crossing, Park Circus seven points crossing, KC Das More, Exide More, Prince Anwar Shah road crossing, Khidirpore crossing, Thakurpukur, Gariahat, Mallick Bazar crossing, Ruby Hospital More, Kalighat metro station have been selected for the study based on the center of urban facilities.

3. Methods and Methodology

The evaluation of traffic performance is important to treat congestion and as well as to select the best route. Traffic speed, travel time index and delay rate of selected roads have been measured to identify the performance of traffic (Roess et al., 2011). Travel time is the time it takes to travel from the place of origin to the destination (Hartanto Susilo & Imanuel, 2018; Karuppanagounder & Muneera, 2017; Lomax, 1990; Lomax & Schrank, 2005; Rao, & Rao, 2012). Travel time for every road has been measured through Google traffic maps in peak and off-peak hours. Google Maps can provide travel time along the road from origin to destination in both peak and off-peak hours (Sahu et al., 2021). Travel time of each selected stretch has been collected for three modes bike, car and bus because these categories of vehicles occupy the major proportions of traffic composition in Kolkata (KMDA, 2008). The average traffic speed of selected stretches has been calculated based on collected travel time data. Traffic delay is the time difference

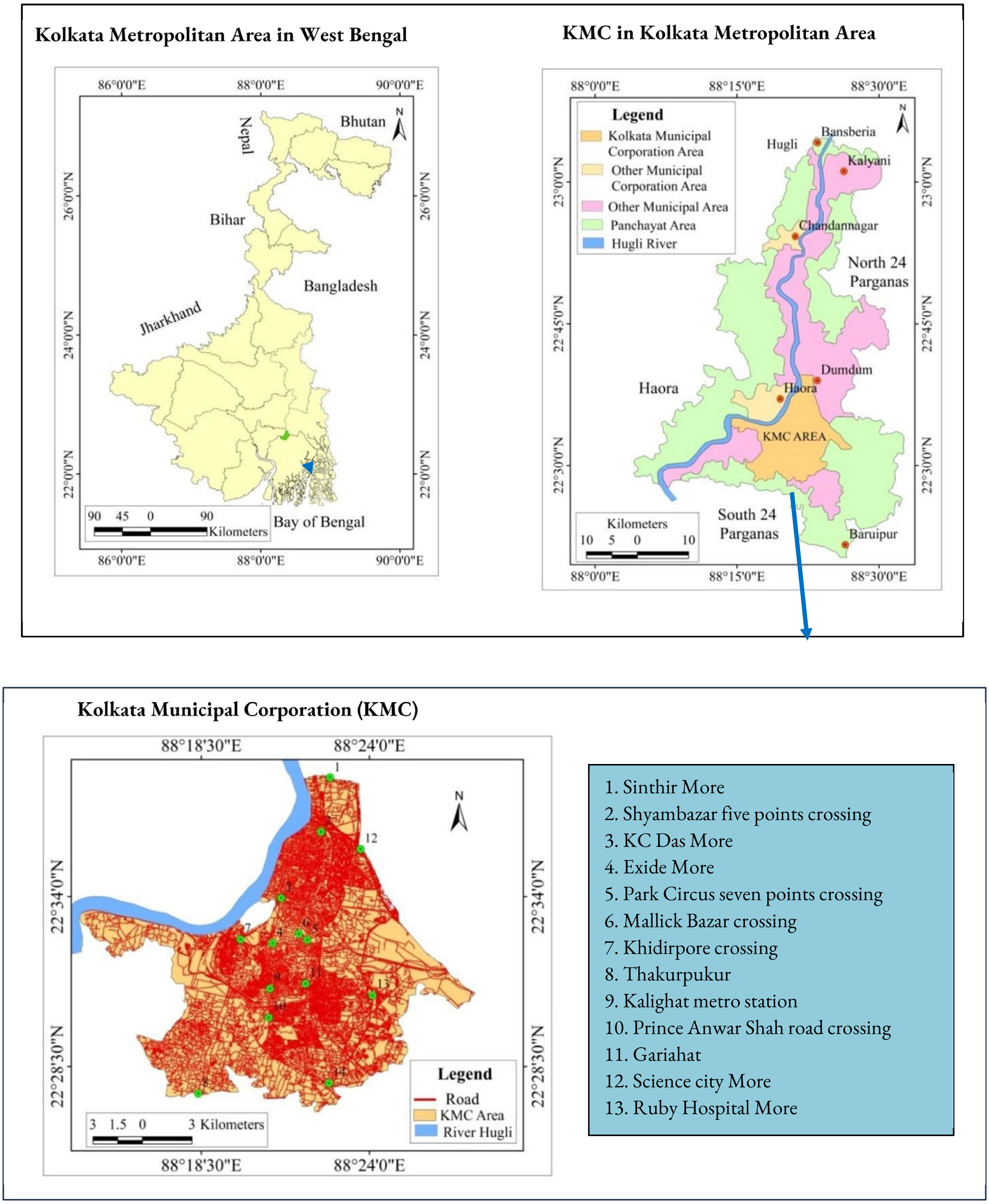

Fig.1 Location map of the study area   Source: NATMO, KMC

between the actual travel time and acceptable Travel Time (Babu, 2017; Dey, 2016; Lomax et al., 1997). For estimating the traffic delay field survey was conducted at intersections along the shortest and alternative routes. Road network data of Kolkata were downloaded from OSM (Open Street Map) data using the QGIS online service application. The data contains an attribute to store the length, direction and time required to travel over each road. Road capacity, traffic volume, and traffic speed vary on different categories of urban roads. But in real situations, traffic volume is not matched with road capacity, consequently, traffic speed is being reduced in Kolkata. So, the selection of the best route is essential to reach the destination faster than other routes. Best route selection not only depends on distance but also on travel time and delay. Therefore, the calculation of the travel time index and delay rate is required for the selection of the best route. A Topology denotes the relationships between spatial objects (Bhatta, 2011). The arrangement and connectivity of a network are known as its topology (Kisgyorgy & Vasvari, 2014; Saxena, 2005; Chen et al., 2021). A topology of the road network has been built using topology rules through ARC GIS 10.3 to get good analysis and results. Then, the Network analyst extension was used in ArcGIS to create the network dataset. The road network data set can perform the route analysis efficiently (Ahmed et al., 2017). A transport network is a set of nodes and edges (Saxena, 2005). The spatial pattern of the network is important to understand the structural attributes (Taaffe et al., 1973). A well-connected network has many short links, numerous intersections, and minimal dead-ends providing continuous, direct routes to destinations. Various indices used for evaluating the connectivity pattern of road transport networks are Alpha Index, Beta Index, Gamma Index, Eta Index (Kansky, 1963) and Network Density. The ratio of the number of circuits present in a network to the maximum number of possible circuits in the same network is called the alpha index. It measures how well circuits has developed in a network (Arif & Gupta, 2020; Nagne et al., 2013; Patra et al., 2019; Rodrigue & Jean-Paul, 2006). The Beta index is expressed by the relationship between the number of edges over the number of nodes that exist in the transportation network and is indicative how complex is the existing network (Al-Dami, 2015; Dutta & Mistri, 2012; Dasmahapatra, 2023; Rahman & Kumar, 2023). The Gamma index is the measure of the percentage of the area connected using the ratio between the actual number of edges to the maximum number of edges of the network (Kundu & Basu, 2015; Nagne & Gawali, 2013; Robinson & Bamford, 1978; Sarkar & Ray, 2021). Network density (ND) is the length of the links per unit area. The higher value of ND indicates a more developed network. In other words, the higher network density value indicates a denser road network and also refers to a better transport system (Daniel et al., 2020; Li et al., 2019; Nagne & Gawali, 2013). Connectivity and accessibility have been measured in this section using graph theory and GIS. The spatial pattern of the transport network of Kolkata has been identified based on alpha and gamma index values. The major three network patterns are spinal, grid and delta pattern (Bora & Baruah, 2019). The spinal and delta pattern refers to the minimal and maximal connectivity respectively. The Grid pattern is characterized by an intermediate situation between the spinal and delta patterns (Daniel, 2021; Haque & Alam, 2020; Patra, 2015). GIS-based Network Analyst is a powerful extension that provides network-based spatial analysis including routing, travel directions, closest facility, and service area analysis (Kumar & Kumar, 2016). The existing network is characterized by peak hour congestion (Chowdhury, 2015) and consequently shortest route, alternative route, and best route identification are required to avoid traffic congestion. The shortest route is a route between two vertices *or* nodes (origin and destination) with minimum distance, time, or cost depending on which factor is being minimized. Here, the shortest route has been determined based on minimum distance. An alternative route is another route between the same origin and destination. An alternative route has been determined for providing the travel option to road users (Ghosh & Mondal, 2019). The best route has been identified from the shortest and alternative routes to avoid the travel delay and minimize total travel time.

4. Result and Discussion

4.1. Road Network Analysis of Kolkata

Road transport is the most important transportation mode for intra and intercity journeys. So, mobility in Kolkata depends largely on a smooth and efficient road transport system. Analyzing the existing road network is fundamental for conducting the best route analysis because it provides the context and constraints within which route options must be evaluated. Without considering the situation of the road network, it would be challenging to identify optimal routes that balance factors such as travel time, distance, traffic conditions etc. Normally accessibility increases with the increase in connectivity (Rahman & Kumar, 2023). A network with high connectivity can provide more alternative routes between origin and destination. However, traffic delay increases with the increase in connectivity (Kumar et al., 2017). Traffic congestion is one of the major problems of Kolkata. So, in this situation selection of the best route is more important than the shortest route and alternative routes. Analysis of the best route is not possible without stating the situation of the existing network.

Various road network indexes have been calculated based on the existing road network in the whole KMC area (Fig. 2 & 3). The Eta index has been calculated to examine the utility of the road network in the KMC area. The value of the Eta index indicates that the average length of an edge of the road network is 0.069 km. The beta index determines the complexity of the network and indicates the number of edges per node in a transport network (Levinson, 2012; Sarkar, 2013). Beta value 1.38 indicates that the network has a complex structure. The alpha index uses the concept of a circuit – a finite, closed path starting and ending at a single node (Dill, 2004). The Alpha Index reflects the proportion of circuits that have developed within the given network. The value 0.194 indicates that not many circuits have developed amongst the selected road network within the city. The alpha index value shows that the transport network of Kolkata is a Grid configuration (Patra, 2015). The grid pattern is the transitional stage of network growth between minimal and maximal connectivity. Here, the Gamma Index value is 0.46 which means that the area is 46 percent connected in terms of the selected roads indicating moderate connectivity. The road network density value is 17.17 km/ sq.km and the average distance between intersections is 96 metre (Table 1). This theoretical road network connectivity has been evaluated regarding present problems of Kolkata like road accidents as it is directly and indirectly correlated with traffic congestion.

The major three network patterns spinal, grid and delta patterns can be identified based on the Gamma and Alpha indices in the city. 0.3 to 0.5 gamma index value and alpha value 0 indicates the Spinal Pattern network which means minimal connectivity. The gamma index value of 0.66 to 1 and alpha index value of 0.5 to 1 indicates the Delta Pattern network which means maximal connectivity. Gamma index value of 0.5 to 0.66 and an alpha index value less than 0.5 indicates the Grid Pattern network which means the transitional stage of network growth between Spinal and Delta Patterns (Patra, 2015). The spinal and delta pattern network indicates the minimal and maximal connectivity respectively, while the Grid pattern indicates an intermediary condition. The wards characterized by high connectivity are found in the central part of Kolkata while low levels of connectivity are found in wards located at marginal parts of the city (Haque and Alam 2020). So, uneven spatial development of road infrastructures is found in the KMC area.

4.2. Best Route Analysis in Peak Hour Situation

It has been found that most of the arterial roads in the KMC area face the problem of traffic congestion during peak

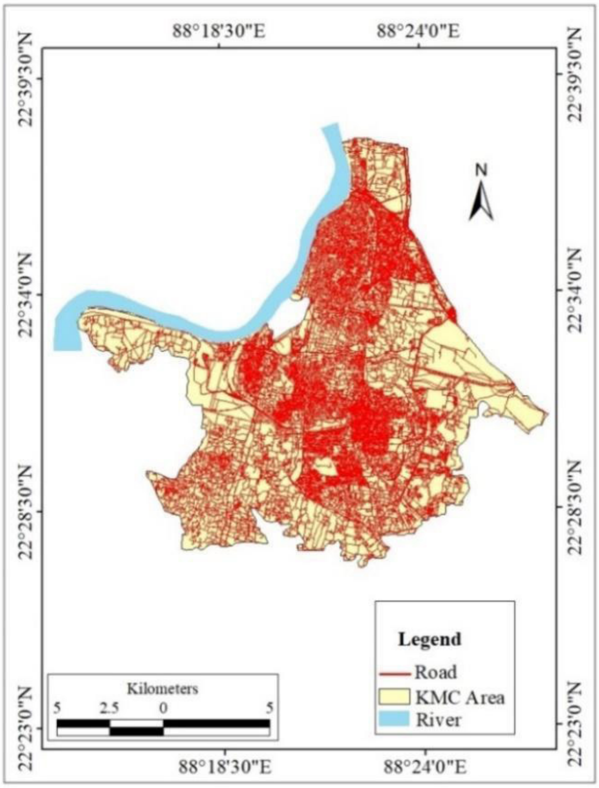

Fig. 2 Road Map of KMC Area
Source: OSM Data

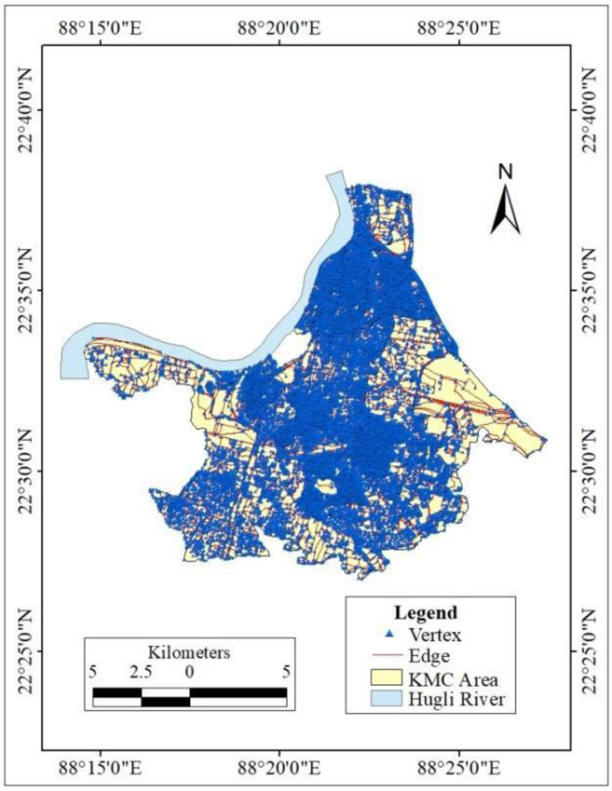

Fig. 3 Road Network Dataset of KMC Area
Source: Prepared by Authors based on OSM Data

Table: 1 Measure of Connectivity Index of Road Network in KMC Area

SL No	Index	Formula	Explanation	Value
1	Eta	$\eta = \frac{M}{E} = \frac{M}{E}$	M= Total network distance E= Number of edges	0.069 km
2	Beta	$\beta = \frac{\sum e}{\sum v}$	e= edges v= vertices	1.389
3	Gamma	$\gamma = \frac{e}{3(v-2)}$	e= edges v= vertices	0.463
4	Alpha	$\alpha = \frac{e-v+1}{2v-5}$	e= edges v= vertices	0.194
5	Network density	Network Density $= \frac{M}{A} = \frac{M}{A}$	M= Total network distance A= Total area	17.177 km/ sq. km
8	Average Distance between Intersection	Average Distance between Intersection $= \frac{L}{N} = \frac{L}{N}$	L= Total network distance N=Number of vertices	0.096 km

Source: Calculated based on Road Network Data set (Obafemi et al., 2011; Nagne & Gawali, 2013; Sreelekha et al., 2016) hours. Heavy traffic congestion occurs at the traffic intersection points, particularly because of the waiting period at these junctions generated by the traffic signaling system. That is why traffic congestion or very slow movement of traffic is inherent with the increase of traffic intersection points on a particular road. However, traffic speed also depends on other factors like the number of traffic lanes and the width of the carriageway. Total fourteen major traffic points located across the KMC area have been selected for route analysis. These points have been selected based on their locational variability and also being characterized by several urban facilities like health, administration, diversification of transport mode, business, etc. The shortest routes among these points have been identified to save travel time and cost in emergencies and also in day-to-day trips. The shortest route analysis has been performed through GIS based on the route distance. But traffic congestion is one of the major problems in Kolkata. Congestion has a negative impact on the economy and environment. Congestion reduces the traffic speed which enhances the travel time even in the shortest route than the other routes. Alternative routes are also identified to avoid traffic congestion on the shortest routes. So, logically best route analysis became necessary to get a comparatively smooth journey. The best route has been chosen from the shortest and alternative routes based on travel time. Travel time might be reduced between two points using congestion-free routes even having longer distances than the shortest route due to the high speed of the vehicle. So, best route analysis is required in metropolitan cities like Kolkata to ensure fast movement in the city. Many studies focused on travel distance, travel time and congestion for the selection of the optimum or best route (Dalip & Kumar, 2016; Tamin, 1996). In Kolkata, travel time between origin and destination has been increased from off-peak hour to peak hour. Travel time is not only dependent on distance but also on traffic speed which is controlled by the congestion level of each road. So, minimum travel time is more significant than the physical distance in a congestion situation to reach the destination from the origin. Traffic delay rate (DR) and travel time index (TTI) efficiently evaluate the travel time and congestion (Dey, 2016). The difference between the travel time required to cross a specific distance during peak and off-peak periods is called Delay Rate which was developed by Lomax et al., (1997) based on travel rate. The travel time index determines how greater the peak period travel time is than the free flow travel time on a fixed road segment (Lomax et al., 1997). The best route between nodes has been identified based on traffic delay rate (DR) and travel time index (TTI) value. A higher Delay Rate value indicates more congestion levels within the road segment and a higher Travel Time Index value signifies the higher severity of congestion on a road stretch (Table 3). It has been found that the delay rate of the journey increased with the increase in the number of intersections per kilometer length (Table 2). So, the number of intersections also influenced the selection of the best route. The shortest route between Garia and the VIP Bridge is EM Bypass. The traffic speed is comparatively higher along the EM Bypass than the alternative road that runs through the heart of the KMC area. SCM road and Park Circus connector road are the directions of alternative routes. The DR and TTI values are lesser in the shortest route than the alternative route because the road width is high and the number of road intersections is low in the EM Bypass. So, the best route is EM Bypass. The alternative road between these two intersections takes 42 minutes extra time (Fig. 11). The shortest route from Sinthi to Shyambazar five-point crossing is the BT Road. The average traffic speed of BT Road is 15.88 km/ hour. RG Kar, Manmathon Dutta road, Raja Manindra road and BT road are the direction of alternative roads. Here, the shortest route is the best route because DR and TTI values are higher in the alternative route than the shortest route (Fig. 4). APC road is the shortest route between Shyambazar five points and Park Circus seven points crossing. Bidhan Sarani, Lenin Sarani, APC road, Parikshit Roy road, Convent road and CIT road are the directions of alternative roads. The traffic speed of the alternative route of APC road is comparatively high at no major crossing lies in this route. Moreover, APC road faces heavy traffic congestion at Moulali crossing and the waiting period at the traffic signal is also over 1 minute in each direction. So, an alternative route is the best route to reach the destination from the origin (Fig. 5). CR Avenue is the shortest route from Shyambazar five points crossing to KC Das More. Bidhan Sarani and Lenin Sarani are the directions of alternative routes. Here, an alternative route is the best route because the DR and TTI values are lesser in the alternative route than the CR Avenue (Fig. 6). Jawahar Lal Nehru road is the shortest route between KC Das More and Exide More. The traffic speed of the alternative road is higher than JL Nehru road but the alternative route takes an extra 7 minutes due to its greater length, thus Jawaharlal Nehru road is the best road between KC Das More and Exide More (Fig.7). The shortest route from Exide More to Prince Anwar Shah road crossing is SP Mukherjee road. AJC Bose road, Sarat Bose road and Southern Avenue are the directions of alternative routes. The traffic speed of the alternative route is high but takes extra time due to the greater length of the alternative route. SP Mukherjee road statistically derives to be the best route from Exide More to Prince Anwar Shah road crossing though during peak hours preference for an alternative route which has fewer crossings is seen (Fig. 8). Diamond Harbour road is the shortest route between Khidirpore crossing and Thakurpukur. Jemslong Sarani is the alternative route of DH road. The traffic speed on alternative roads is high and the length is approximately the same. That is why an alternative route saves 1 minute of travel time. Here, Jemslong Sarani shows better movement between Khidirpore Crossing and Thakurpukur (Fig. 9). Subodh Chandra Mallick road is the shortest route between Park Circus seven-point crossing and Garia four-point junction. The alternative road of SCM road is the EM Bypass and EM Bypass connector road. The alternative road saves 2 minutes of travel time due to high speed. Here alternative route is the best route between Park Circus seven points crossing and Garia four points junction (Fig.10). AJC Bose road is the shortest route between Mallick Bazar crossing and Khidirpore crossing. Although the traffic speed of alternative road is high but it takes an extra 2 minutes of travel time since it is lengthier. But as DR and TTI values are higher in AJC Bose road the lengthier alternative route is the best route (Fig. 12). RB Avenue is the shortest route between Ruby Hospital More and Kalighat metro station. Most of the length of RB Avenue is under slow traffic movement. The alternative road of RB Avenue has low traffic speed and route length is high. So, the alternative route runs 8 minutes extra travel time. So, though slow traffic movement is experienced along RB Avenue it is the best route between Ruby Hospital More and Kalighat metro station (Fig. 13).

Table 2: Impact of Intersections on Delay Rate

Corridors Name	length in km	Total No. of Intersection	No. of Intersection/ km	Delay (Second)
APC-BT	10.23	58	6	904
NSC-SP	13.36	72	5	700
DH-Khidirpur	15.07	52	3	660
CR-BT	8.82	66	7	1122
SC-Gariahat	13.88	73	5	600
EM Bypass	15.65	46	3	420
AJC - EM Bypass	10.45	34	3	380
RB Ave- EM Bypass	12.44	48	4	620

Source: Calculated by the authors based on Google Live traffic; (Maparu & Pandit, 2010), Primary Survey

Table 3: Determination of Best Route

Origin and Destination	Shortest Route		Alternative Route		Best Route
	Delay Rate (in Second)	Travel Time Index	Delay Rate (in Second)	Travel Time Index	
Sinthi More to Five Points Crossing	180	1.21	420	1.47	Shortest
Five Points to Seven Points Crossing	724	1.57	540	1.36	Alternative
Five points to KC Das More	522	1.67	420	1.39	Alternative
KC Das to Exide More	420	2.17	600	1.90	Shortest
Exide More to Prince Anwar Shah Road Crossing	300	1.36	420	1.44	Shortest
Khidirpore Crossing to Thakurpukur	540	1.35	240	1.13	Alternative
Seven Point to Garia Four Points Junction	600	1.42	360	1.23	Alternative
Garia to VIP Bridge	420	1.23	2280	1.90	Shortest
Mallick Bazar Crossing to Khidirpore Crossing	240	1.36	180	1.21	Alternative
Ruby Hospital More to Kalighat Metro Station	480	1.53	780	1.72	Shortest

Source: Calculated by the authors based on Google Live traffic map; (Maparu and Pandit, 2010), Primary Survey

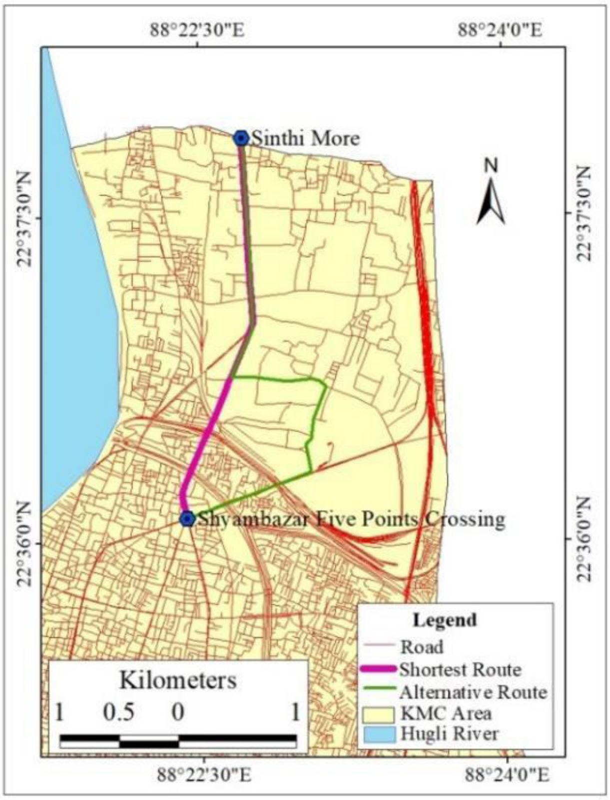

Fig. 4 Shortest and Alternative Routes between Sinthi More and Five Points Crossing

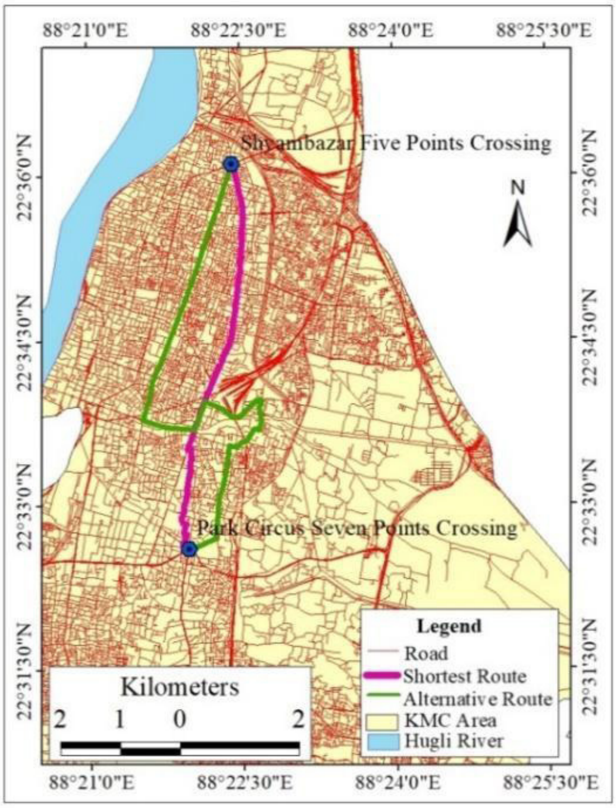

Fig. 5 Shortest and Alternative Routes between Five Points and Seven Points Crossing

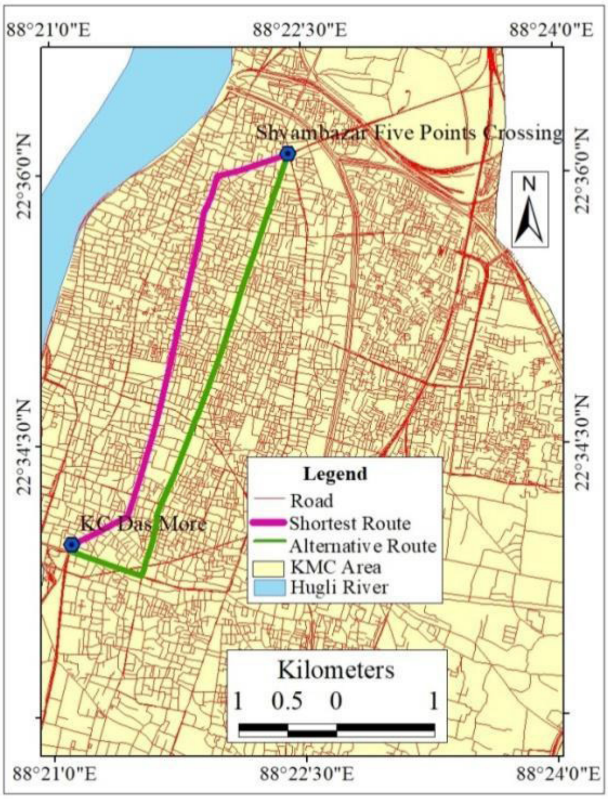

Fig. 6 Shortest and Alternative Routes between Five Points and KC Das More

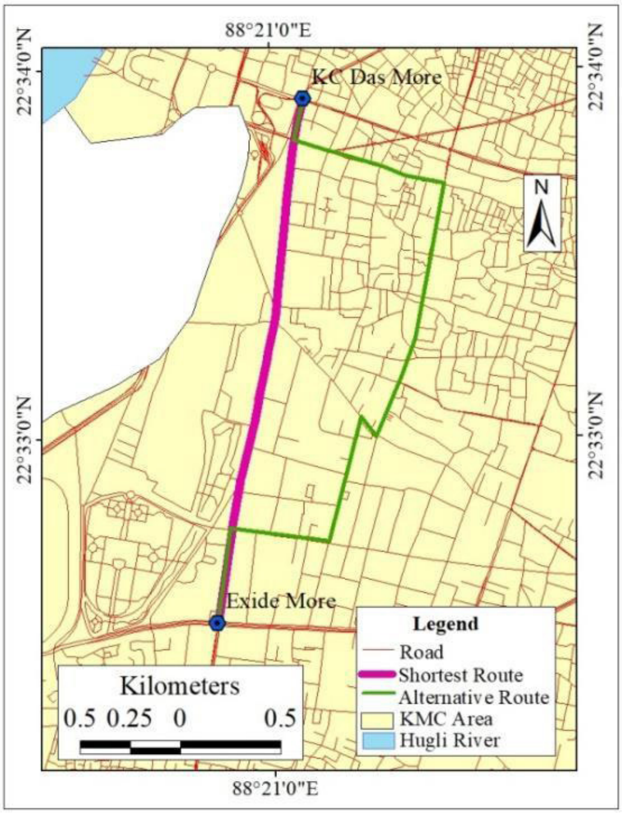

Fig. 7 Shortest and Alternative Routes between KC Das More and Exide

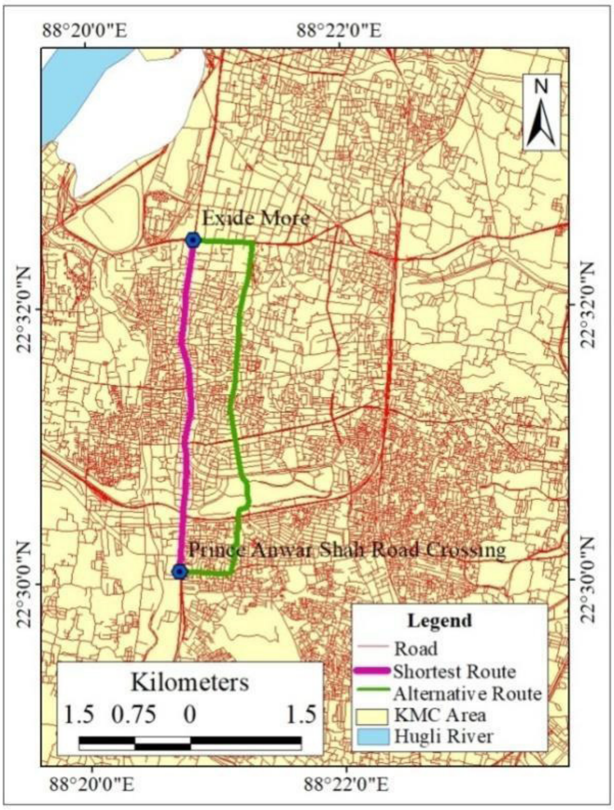

Fig. 8 Shortest and Alternative Routes between Exide More and Prince Anwar Shah Road Crossing

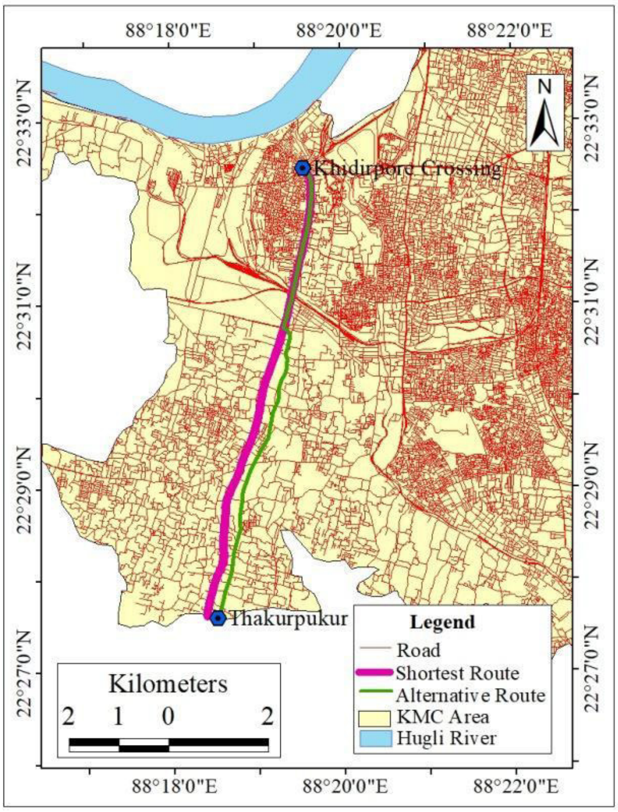

Fig. 9 Shortest and Alternative Routes between Khidirpore crossing to Thakurpukur

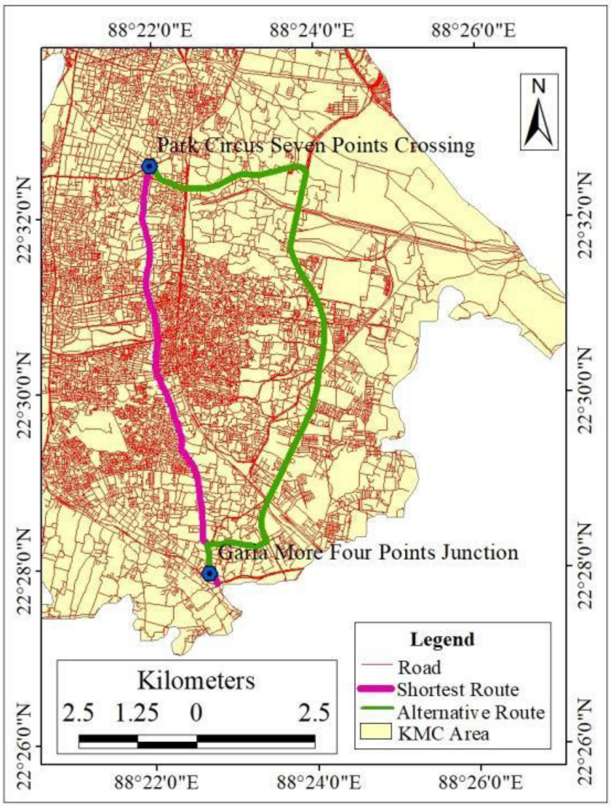

Fig. 10 Shortest and Alternative Routes between Seven Points Crossing and Garia more

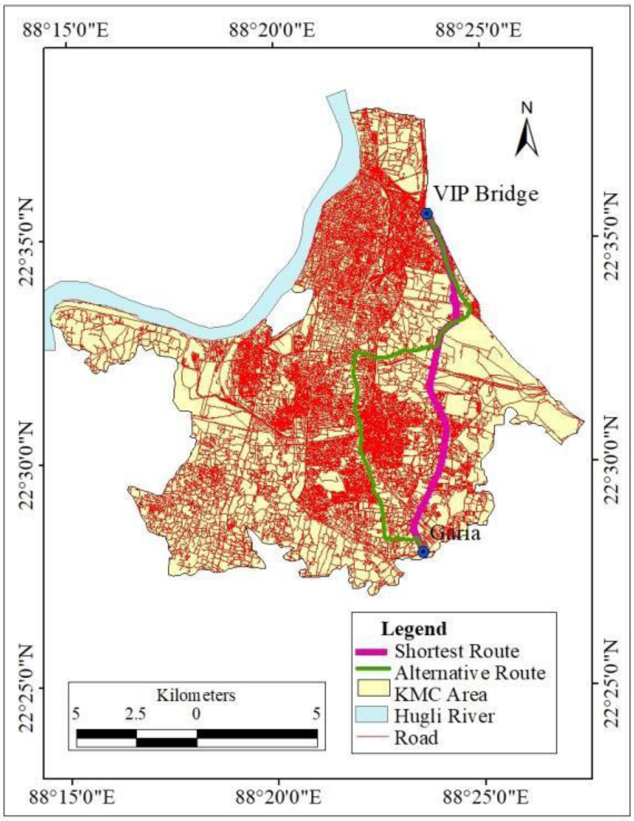

Fig. 11 Shortest and Alternative Routes between VIP Bridge and Garia

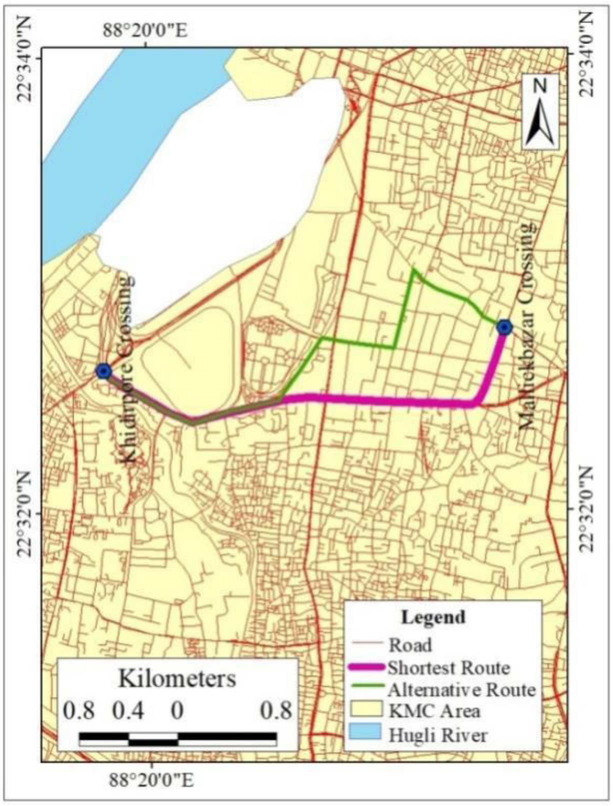

Fig. 12 Shortest and Alternative Routes between Mallick Bazar Crossing to Khidirpore Crossing

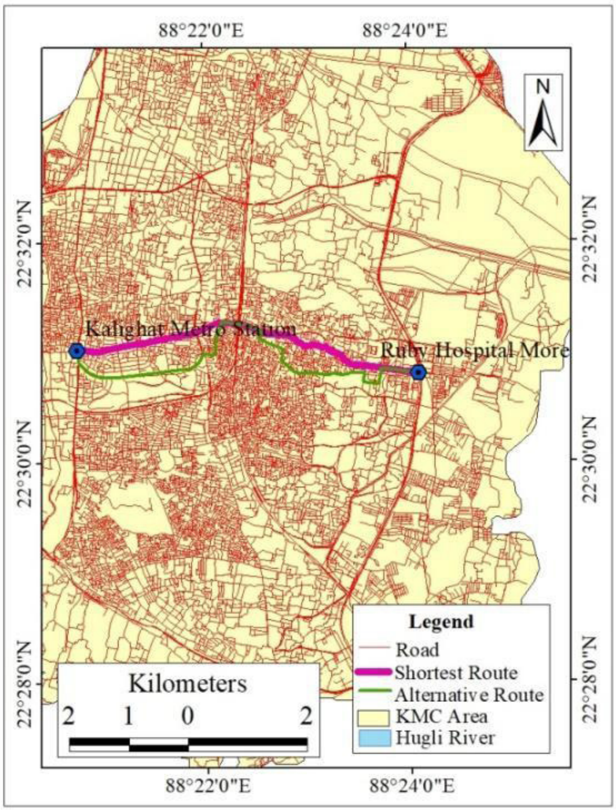

Fig. 13 Shortest and Alternative Routes between Kalighat and Ruby More

5. Conclusion

The best route ensures security in emergencies and comfort in common journeys in the context of urban traffic congestion. This study analyses that the time distance of roads is more significant as compared to the physical distance when movement in congested roads are concerned. Yet, shortest distance routes have been identified as the best route despite increased travel time during peak hours along them in 50 percent of cases as alternative routes to them are also affected by traffic congestion in peak hours. Nevertheless, it cannot be overlooked that in a city like Kolkata where congestion on roads is a daily event, in cases of emergency like accidents and urban fire following alternative routes is the best possible solution. So, the present study suggested to general road users that identification of the best route from the shortest route and alternative routes is necessary knowledge to be incorporated into a journey plan. Further, as determined from the analysis the number of road intersections has a great impact on the delay rate (including traffic signaling waiting period along with section delay) avoiding intersections as much as possible by using flyovers and subways may ensure faster movement between origin and destination. However, it should be understood that identification of the best route can save travel time comparatively, but it cannot solve the challenges of congestion permanently.

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