Transportation Planning through GIS and Multi-Criteria Analysis: Case Study of Beijing and XiongAn

Abstract:

Urban population growth and urbanization require technological innovation in order to address the challenges posed by transportation. Identifying transportation capacity (road and railways) is an important task that can identify whether the network is capable of sustaining the present volume of traffic and whether it can handle the future intended traffic flow. A new city, XiongAn, will be built in the coming years in order to relieve the pressure of population on Beijing and transfer the economic growth, business activity and opportunities across the country. The focus of this research is to generate a transportation model between Beijing and XiongAn, in order to increase connection and connectivity, reduce travel time, and increase transfer capacity between the two hubs (Beijing-XiongAn). The existing transportation network between two cities is analyzed and a network which can handle future demand has been proposed. The first stage has been investigate a variety of options using geographic information system (GIS), while in second phase the important criteria for the assessment and prioritization of the options using Analytic hierarchy process (AHP) for evaluation of different options of mass transit system including existing railway intercity line; a new railway high speed line; and motorway options. The options were evaluated using various criteria responsible for selection of alternative, it is found that travel time, cost of travel, safety, reliability, accessibility and environment are key criterion for selecting best alternative. The GIS and multi criteria analysis suggested that the best option is to build a new high speed railway line.

Keywords: ArcGIS, AHP, transportation planning, road, railway line, connection, connectivity

Introduction

The economic growth and urban development of any city depends on its transportation network. Transportation planning is a complex process involving careful forecasting of future needs and study of existing travel pattern in cities. Innovations in transportation planning and development has put pressure on developers and planners to update their toolkits to cope with the emerging challenges [1]. They need to develop a more balanced view of accessibility [2] and mobility [3]. Expansion of the transit network and the consequent increase of human activity is a complex process which needs to be integrated with multi-purpose land use and minimum effects on the environment [4], [5], [6]. Smart sustainable transportation awareness is increasing day by day, so the majority of planners agree that transportation plays a key role in solving the congestion problems. Solving the problem in this way is a continuous long-term process whose impact will be visible only in the long term [7]. Many cities around the world are expanding and the demand for transportation is increasing, placing planners under great pressure [8]. Inadequate knowledge, unjustifiable assumptions in modeling, uncertainty regarding model validation and lack of transparency has led to considerable skepticism with planning [1]. The lack of suitable and integrated approaches strongly affects the quality and reduces the attractiveness of transit networks in developing countries [7]. Lack of robust transportation models, planning and traffic forecasting, inefficient land use and inefficient relationships between different means of transportation, and inaccurate analysis of supply and demand are basic recurring problems in many developing countries [9]. Due to the different mindsets of transportation planners, many priorities such as cost-benefit analyses and environmental impact assessments remain unresolved and put the overall plan at serious risk [1].

China is leading the world in high-speed rail network capacity, with 16,000km of track in service, passenger volume of 2,122,992 million, and 40.99 billion tons of freight a year [10]. The passenger has different preferences depending on distance and time [11]. The unreliability of the time needed to travel by road has become a major concern from the perspective of the traveler, whose experience of the same trip varies from day to day [12], [13], [14]. In assessing rail capacity, it is possible to define the maximum number of trains that can pass a bottleneck section in a fixed period of time. The performance of any transportation system is limited by its own capacity [8], [15], [16], [17], Chinese cities are still struggling with air pollution problems. A study found that from 2006 onwards rail transportation is playing an integral part in environmental recovery and has a significant positive impact in China [10].

Accessibility and connectivity are the most important parameters to consider in establishing an integrated transportation network in a city. The initial step is to analyze and understand the existing transportation network and seek to utilize resources more efficiently rather than just to extend the network [11]. The growth of the Chinese economy places the transportation system under pressure. The higher demands and environmental factors makes the problem more complex [10]. Land use and transit ridership have a strong correlation in Beijing. Places of interest increase the attraction of passenger volume and are therefore a factor to be considered by the urban planner and transportation planner [18]. Transit travel time reliability has become a very hot topic for research in recent decades due to congestion [19]. Beijing passenger volume affects consideration of many aspects such as travel mode selection, travel time, and travel length, safety and comfort [18]. Road emits more pollution then railways, hence the demand, capacity, and environmental cost of the railways is much lower than that of roads [20]. Study analyzed that 15-20% US land is used by road networks while in China road network carry 19% land. [21], [22].

Urbanization increases the number of automobiles and mileage of road and increases the pressure to invest more money in the auto industry to increase GDP [23]. The rapid expansion of the road network is considered the major factor affecting sustainable development in China [24]. Urbanization is catalyst in increasing automobile manufacturing, vehicle ownership, expansion of road network and social interaction [23]. Road network effects the social networking and interaction, while Social life is widely effected by transportation facility available in the cities [25]. Many research studies have found that the expansion of road transportation results in the increase of vehicle ownership , energy use, and higher emission levels, increasing congestion, separation effects due to the road, a vehicle-based society and inefficient usage of available resources [26], [27], [28], [29], [30], [31], [32], [33].

Each 1 percent increase in GDP for road transportation is responsible for an increase in energy consumption of 0.33 percent and 1.26 percent of urbanization [23]. Many research studies have found the road network in Beijing is complex and dense, continuous expansion in road infrastructure strongly affects the future development of the city along with increased motorization [4], [34], [35]. Road network structure (either single lane or multi-lane) strongly increases the ecological risk, need for more risk assessment, division, and interference in the regional forest landscape [34], [36], [37], [38]. The expansion of the road network has many adverse effects, such as separation effects, greater ecological risk, an increased level of air pollution, and faster habitat destruction [39], [4].

This research is a case study of the connection between Beijing and XiongAn. The populations of Beijing, Tianjin and Hebei are 22 million, 15.5 million and 74.3 million respectively; and their annual growth rates have reached 16.2%, 14.4% and 11.6% respectively [40]. So there is a huge gap in the development of these three areas, and Hebei needs to sustain almost four times the population of Tianjin and Beijing. This helps explain why the current project is located in Hebei it is hoped thereby to close the developmental gap by providing job opportunities and a boost to the local economy. XiongAn is planned to be built between the present counties of Xiong, Rongcheng and Anxin, from which it obtains the name XiongAn. The newly developed area, also called jing-jin-ji, will connect Beijing, Tianjin and Hebei and is designed to increase the economic activity and reduce the development distance between these 3 provinces.

Urbanization in China is at a peak, and most job opportunities are to be found in new urban areas [41]. XiongAn" is a satellite town to accommodate the over burden population of Beijing [42]. Many studies describe the current state of Beijing as "urban disease", or "urban ill" [43], [44]. Beijing has decided to extend its municipal administration to the border with Tongzhou in Hebei province to reduce the population burden on the capital city [42]. The newly built "XiongAn" will provide population relief for the massive capital city [44]. With the continuous process of integration, Tianjin and Hebei will become more attractive places to work and live [44]. XiongAn is located in Hebei province, which connects the 3 counties of Xiong, Rongcheng and Anxin, as shown in figure 1. The name is derived from the two counties Xiong and Anxin which is XiongAn [45]. The initial developmental plan is for 100km^2 (100km west of Tianjin and 100km southwest of Beijing). After completing the initial development plan, the development will further extend for 200 km^2 and there is long-term planning for 2000 km^2 [46], [43]. XiongAn, located in the southwest of Beijing, is to serve as a developmental hub for Beijing, Tianjin and Hebei, creating an economic triangle (Jing-Jin-Ji) or jingjinji. Located in the Baoding area of Hebei province, it completes a triangle between Beijing, Tianjin and Hebei [47].

Various methods are available for route selection, a route will be considered feasible if it minimizes the overall cost of transportation (operating cost, construction cost, minimum separation effects, environment friendly) and maximizes efficiency, (direct route, shortest travel distance, better accessibility and mobility options) [48], [49]. The use of many criteria is common to many areas of scientific research. In transport this method is used for example to determine the mode of transportation, to estimate the passenger satisfaction, to evaluate the transport projects and for other purposes. Transportation planning and modeling with GIS has made analysis convenient and accessible; many real transportation problems can be analyzed, forecast and simulated with GIS [50]. Launching transportation applications in GIS has increased the usage of GIS for transportation planning and modeling in recent years; now it is referred to by the acronym GIS-T [51]. Technological improvement is continually progressing, and rapid development of geographic information system (GIS) of spatial information technology is used more widely [52], [53], [54]. Studies have found that accessibility, transportation planning, transit network analysis, social economic and environmental implications can be evaluated [55], [56]. GIS can be used to determine the arbitrary analysis or attraction places of user-defined [57], GIS within the field of transportation engineering was developed [58] to analyze the impact of activity trips on regional

transportation patterns. Within GIS now it is possible to the predicate, analyze, forecast, simulate and implement an imaginary transportation model, expansion road network analysis, and regional road network design [59], [60]. High-speed rail transit can reinforce the links between cities, provide a reliable and attractive facility for the passenger, and increase the willingness to travel [61]. Furthermore, although the initial cost of rail transit is higher, the overall operating cost per unit capacity is lower, and there is the prospect of higher passenger comfort, higher safety, a dedicated system, and higher performance as compared to other transportation modes (Light rail and Bus system) [62]. Rail transit can maximize transit ridership, achieve maximum operating speed, and higher efficiency, be environmentally friendly, and increase the options open to the traveler by offering higher network efficiency, higher connectivity and ease of transfer [63].
In sum, the development of a methodology for transport planning by applying both multi-criteria analysis and GIS data analysis taking into account different economic, infrastructure, environmental, technological and other factors has not been sufficiently investigated. This paper offers an integrated approach to planning the transportation between two big cities by taking into account route analysis and multiple factors relevant for transport.

Decision Analysis (Research Methedology)

The research methodology consists of following steps:

- Step 1: Identifying routes between cities using GIS and route analysis
- Step 2. Defining criteria and Prioritization of the routes using the multi-criteria method

The methodology developed to prioritizing the variant routes and the second step of methodology involves multi-criteria analysis. The present research uses the Analytic Hierarchy Process (AHP), developed by Saaty in 1980 [64] assess the weight to be given to the criteria and to prioritize the various routes according to their maximum AHP scores. The AHP method is based on the following principles: structure of the model; development of the ratings for each decision alternative for each criterion; synthesis of the priorities. The pairwise comparisons between each criterion and variant routes are performed using Saaty's scale, [64] [65] [66] (shown in Appendix table 5).

Step 1: Identifying routes between cities using GIS and route analysis

According to "Urban Road Engineering Design Code" (cjj37-2012), urban roads in China is divided into (i) motorways which connect cities with 4 lanes with 100-120km/h, (ii) trunk roads connecting the districts inside the city consist of 4 or more lanes in each direction with speeds of 40-60km/h (iii) secondary roads with 2 to 4 lanes with speed of 30-50km/h, (iv) while branch roads (community roads) have a speed of 20-40km/h with 2 lane roads [67], [68], [69]. The Beijing transportation network is very complex, and spreads across the entire city. GIS data relating to motorways linking cities in China favored having a motorway route in the direction "XiongAn". In a case study for the first phase, we divide the area in the 50km buffer, to determine how much road infrastructure and rail infrastructure is available in the newly developed area as shown in figure 1.

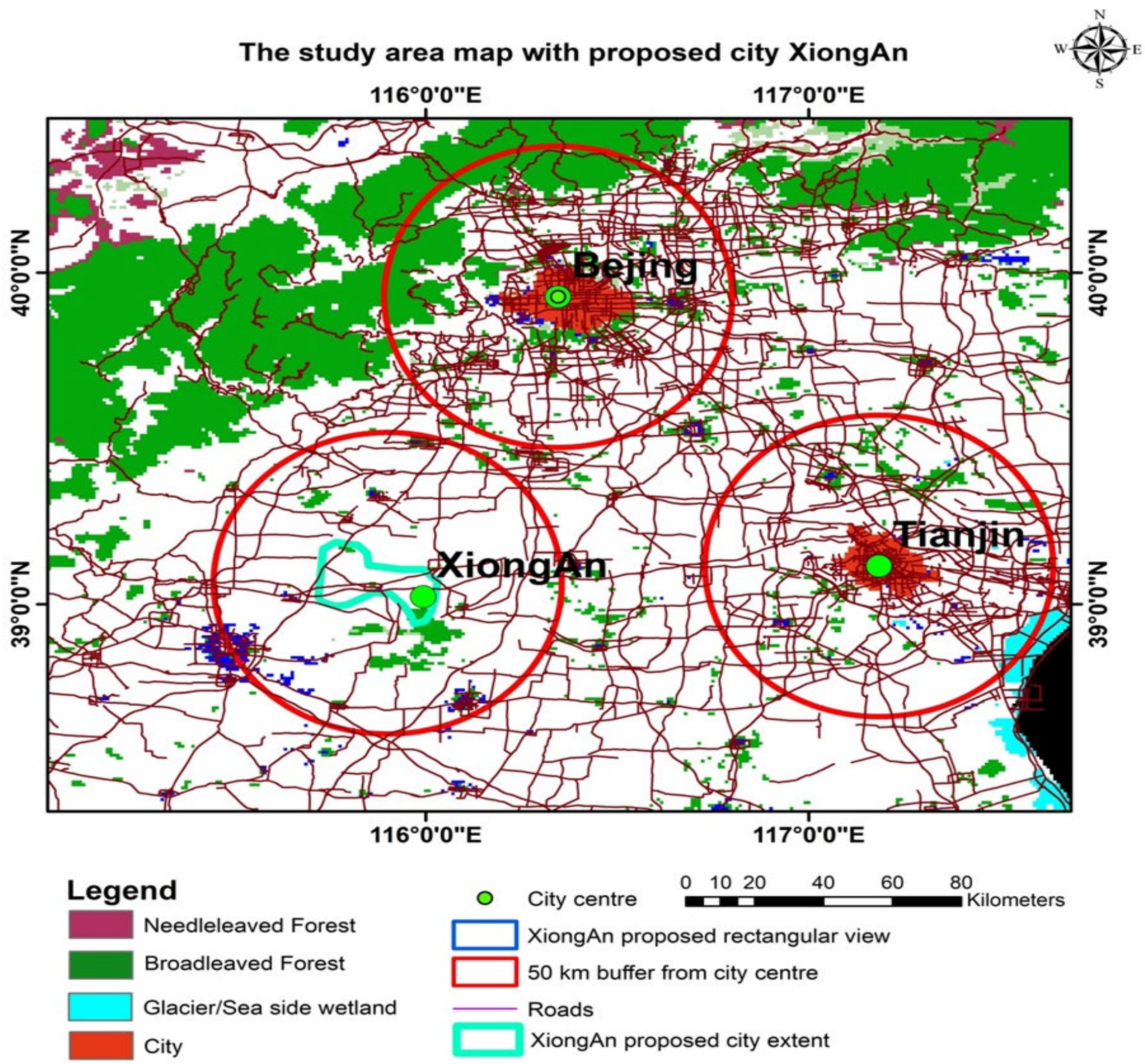


Figure 1, Beijing, Tianjin and Hebei road network map

According to a short route analysis, the distance from Beijing to Xiongan for one route is 125km and for another its 167km from study area 1 as shown in figure 2. A longer route is available from study area 2 via Tianjian and extends to 196km. The expected time in all these routes is more than 2 hours, as estimated from online traffic analysis. The major part of the road consists of express highway where the speed is around 100km/h, while the minor road portion is based on secondary and trunk roads, which mainly pass near residential districts in the city. This proportion of road consists of many intersections and crossings while the speed is not more than 50km/h.

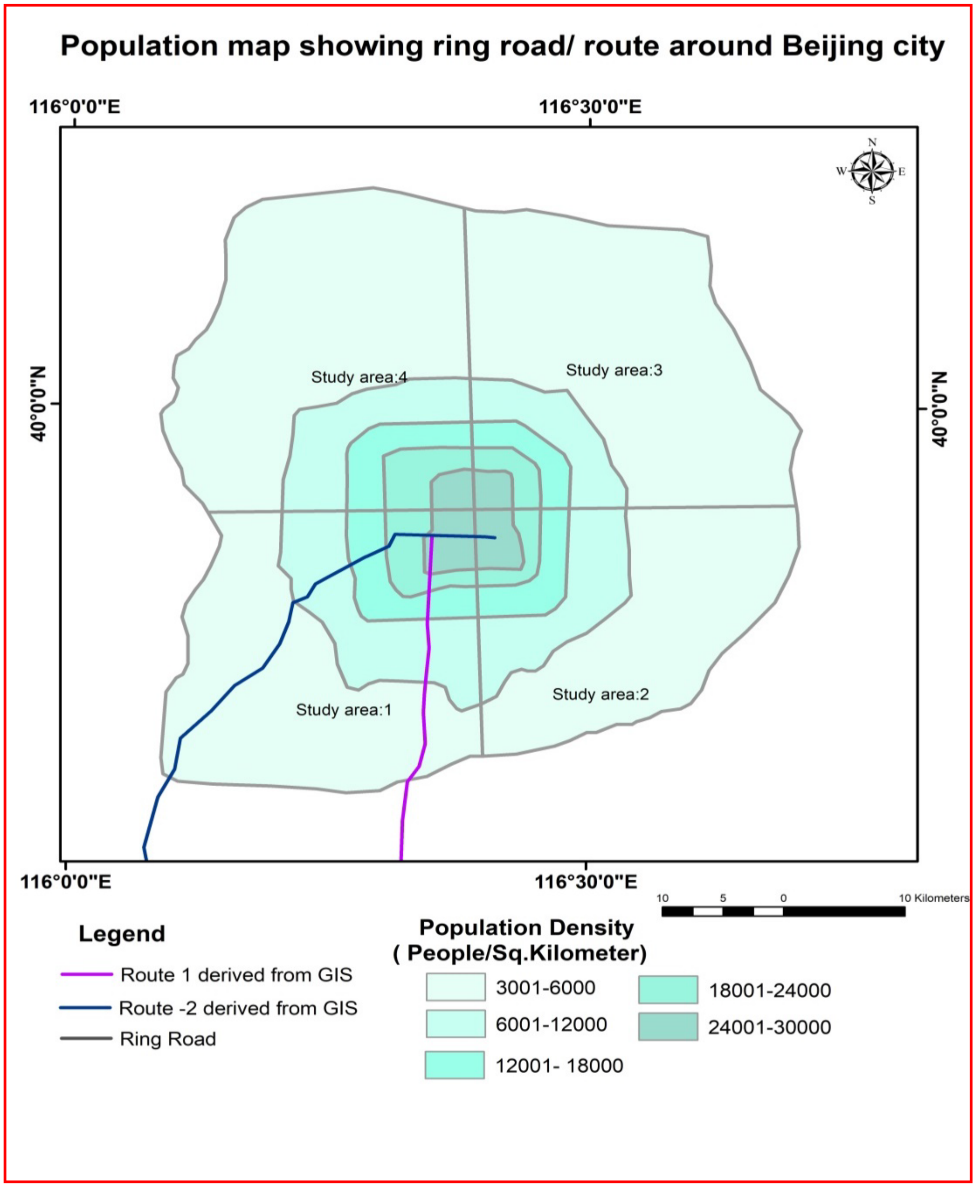


Figure 2, Distribution of Beijing City on the basis of Population and ring road

For a detailed analysis, Beijing city is divided into 4 study areas as shown in figure 2, to measure the road infrastructure from a specified area and to analyze the connection and connectivity within the cities and with the newly developed areas. According to figure 2, the available road network is from "Study Area 1" while there is no connection between study areas 2, 3 and 4. Within the short circular radius study area 2 and area 4 can be connected with study area 1, but there is no connection between study area 1 and 4.

The current system has very weak connection and connectivity in study areas 2, 4 and especially study area 3. Xiongan is located in the north of the city. There is no circular radial connection which gives a short and convenient route for people. Hence Beijing is already facing a higher number of vehicle, air pollution and environmental problems. This study will propose the construction of a new road line from study area 3, which also facilitates study areas 2 and 4. Hence the burden from study area 1, will be reduced. The inhabitants of the capital city will have a fast, easy and convenient route from Beijing to Xiongan. There is one point that is quite astonishing, from short route analysics its measured that a minmum of 2 hour traveeling will take in one direction, this may not attract many people to work or live there in future. Furthermore, the present research proposes a new road from study area 3, along with fast speed railroad. The existing road starts from Qianmen east road. Hence the two suggestions will increase the connection and connectivity between study area 3 and study area 1. This case study suggests a route from the second ring road to Qianmen east road which will increase the connection between the two areas.

Figure 3, Beijing to Baoding Existing Transportation Network (near to XiongAn)

According to figure 3, which represents the transportation route between Beijing and Tianjin, the minimum time needed when traveling by road is more than 2 hours depending on traffic conditions, and with the intercity railway line according to GIS maps and the Beijing station chart the minimum distance to reach to Baoding the area near to Xiongan is more than 3 hour and 30 minutes until 4 hour. A subway line which provides access from second to sixth ring road is also shown in the map; it is 26km long and near the Daxing Area in the south of Beijing. There is no direct rail route between Beijing and Xiongan, and the distance between Baoding and Xiongan is around 55km. but the distance from "Xushui" is 40km from the railway line of a tiny town in the same direction (as shown in figure 3).

Results and Discussion:

This study recommends the following research suggestions:

- A radial railway line is proposed to connect the two cities to increase the connectivity, and to generate higher ridership, provide greater passenger convenience, reduce travel time, reduce traffic volume on parallel highways and meet passenger demand. From the Beijing second ring area in the direction "XiongAn", the available rail track length is 26km at line 4, of which the last stop is Tiangongyuan, which is located in outside of 6th ring road. The road network links in

Beijing is quite widespread and complex [35]**.** The city now requires reduction in traffic and to relieve congestion. This study recommends a high-speed railway line connecting the two cities. Analysis from a survey using the subway application, GIS map and city short route application demonstrates that it takes more than 1 hour 25 minutes to arrive at Tiangongyuan (last station at Line 4). So if the distance of 26km is covered in 1 hour 26 minute on the only available subway line in that direction, the question arises, will it attract people to travel or make them willing to live in the newly developed area?

Another question is how to reach to the newly developing area in a way that is convenient and acceptable to passengers. The total distance between Beijing and XiongAn is around 130km. If this distance is covered within 1 hour, then most of the people will be willing to travel. Hence the usual travel time in Beijing from home to work is in between 45 minutes to one hour, plus time spent in transit network (Travel time) [70].

- A high-Speed Radial line is needed one station of which is located inside each of the 2nd, 3rd, 4th, 5th and 6th ring roads, and the last station lies in the newly built area "XiongAn". The new radial line will follow the major demand directions towards the newly built city. To fit offered capacity the circle Lines 2 and 10 will play a major role in the distribution of passengers across the city. Furthermore the circle lines will be effective distributors for subway and bus lines; furthermore, they will enable suburb to suburb trips to use a radial-circle-radial path. Connection and connectivity within each ring will increase passenger distribution across the city. The transfer from one line to another will be reduced through offering more connectivity through integrated transit planning.

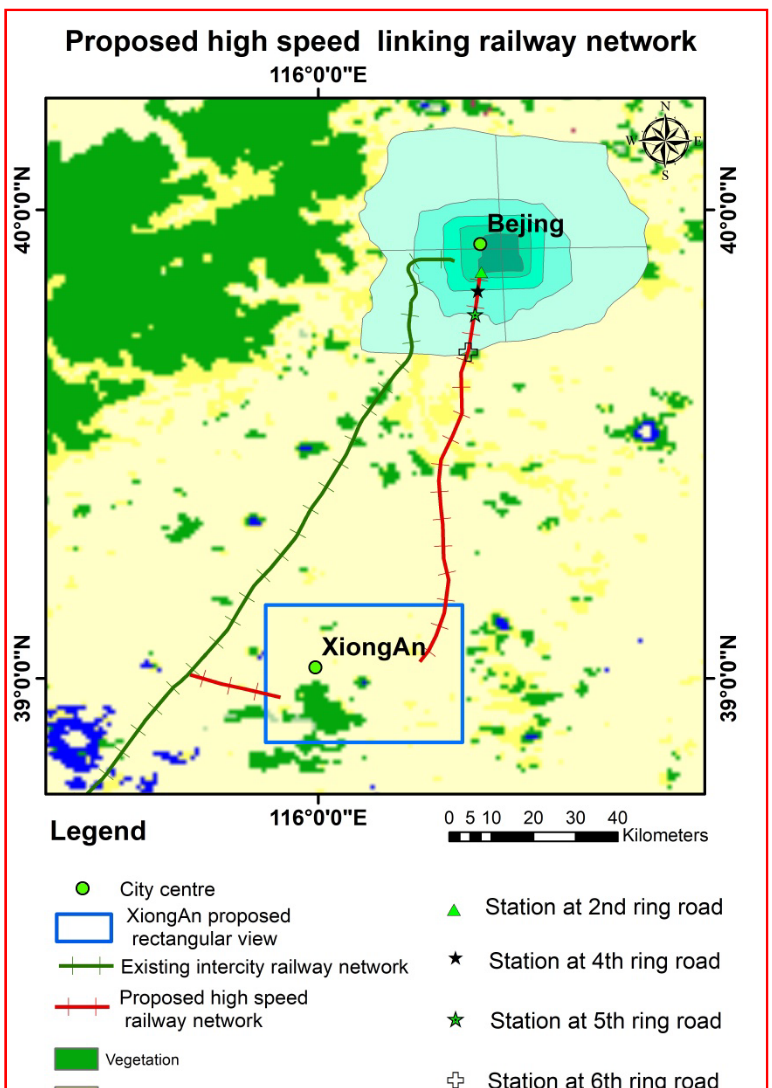


Figure 4, inter-city railway network and Proposed High-speed railway line.

The sole purpose of suggesting the High speed railway line (HSRL) (figure 4) between Beijing and Xiongan is to meet the future needs of inhabitants outside the city. As mentioned in literature review, the initial step is only to consider the 50km^2 area, but in future, the planning can be applied to similar areas in the country. The proposed line for HSRL is shown in the map, where the stations are suggested in 2nd, 4th, 5th and 6th ring roads, so the Beijing subway will work as feeder lines and buses as branch lines in the city.

In the study the following hub options are considered:

Distributed Terminals Network Model for Beijing:

The distributed terminals is to minimize the adverse impacts of Central and Directional Terminals and maximize the effectiveness and efficiency of public transportation. Many countries have the problem of a central based transportation network which increases the travel time and burden on city Centre. Every transit mode originates to and from the Centre. For example Munich, (Germany) is based on central terminal system, but because of a limited population of 1.5 million people [70], [71] 69% of Munich inhabitants uses public transit modes [72], so it is only a problem at peak hours, and functions effectively in low peak hours [73], [74]. The set of terminals in this case essentially comprises existing and proposed metro rail connections through the city. This can provide more accessibility in the city, but the optimum result of the research will not be fulfilled, which is to transport the inhabitants between two cities in a mode in which they are willing to travel. This mode should offer more and ask for less (less transfer, higher connection through the city, ease of reaching the station). Distributed terminals will provide better access facilities to potential HSR passengers. They will also provide city managers with facilities to handle local and regional traffic more efficiently in future to increase connection and connectivity, reduce the number of transfers, offer direct trips, and increase comfort and convenience.

In case study of Beijing, (as the shown in figure 2), the city is located in south of the city, hence the figure 5, present the details to connect the new city with Beijing. For Beijing case study it is assumed that each of the directional corridors will have three access nodes in the HUB area. For example, the corridor connecting the southern parts of the region or other regions in that direction will have its terminal at the northern end of the HUB area, and two additional access nodes, one in the centre and the other at the southern end. Likewise, all the other corridors will have their terminals at the respective opposite ends of the hub area. Corridor 1 as shown in figure 5 (C-1) connecting the Nodes A and G in the same region as Node-A or another passes through Nodes B, C and D in the hub area and Nodes E and F in the region. The terminal for Corridor C-1 is Node A. Nodes A to D are the locations of existing or proposed terminal locations of transport services in the HUB area. Corridor C-2 connecting Node H in the region can be planned such that its terminal in the hub area is at Node C. Likewise Corridor C-3 may have its terminal in the hub area at Node B. Alternatively, Corridors C-2 and C-3 can have a common terminal at Node B or C. Nodes H and I could be in different regions in the respective directions. Distributed terminals provide uniform accessibility throughout the city, combining directional and central terminals.

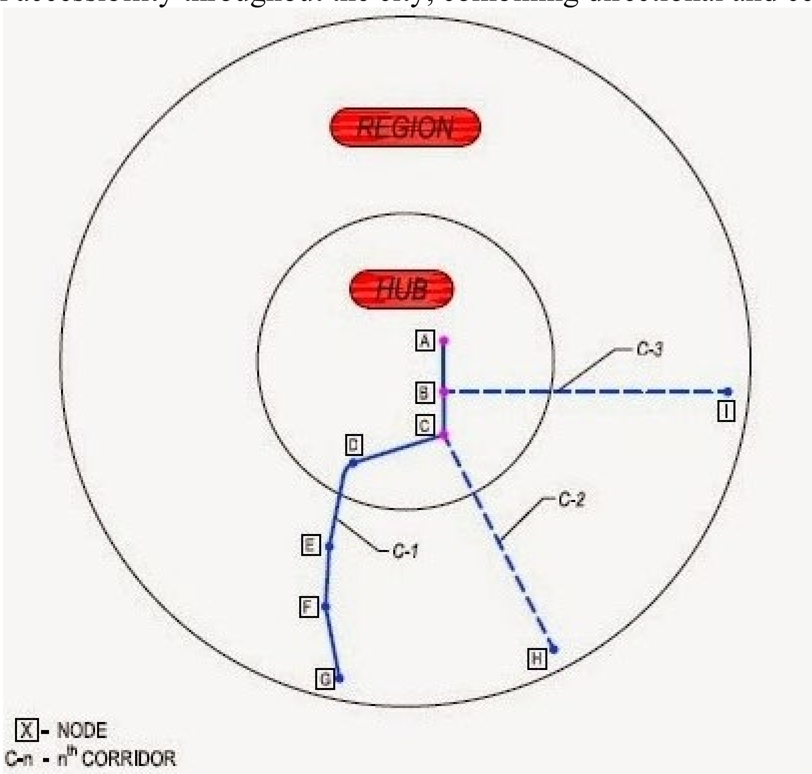


Figure 5, Distributed Terminal Network Concept

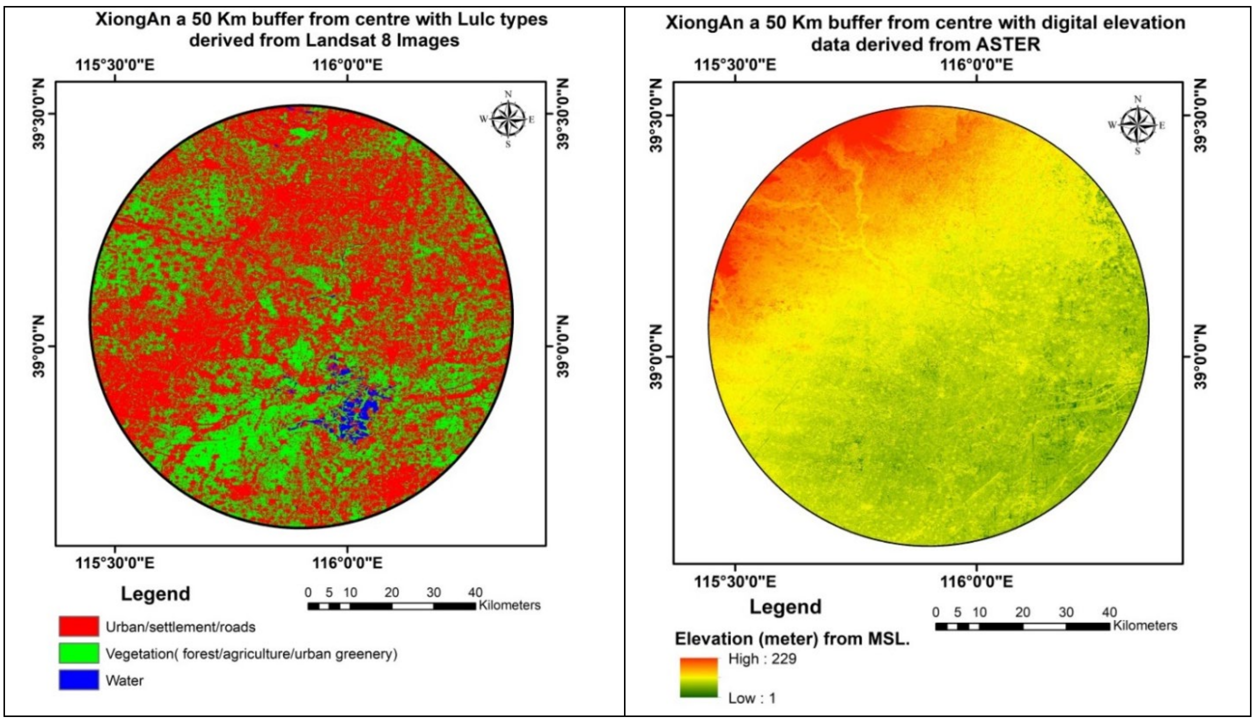
Network integration with well-designed transfer stations is a very important parameter for planning the line between Beijing and "XiongAn". Furthermore, the inconvenience of transfers can be overcome by (i) the overall perceived reduction of travel time (ii) the functional design of lines (iii) passenger attraction / transit attraction factors to be considered (iv) network operating efficiency.

The overall perceived reduction of travel time: Travel time with transfer must be less than travel time by the direct service, People perceive walking and waiting time 2.0 to 2.5 times longer compared to in-vehicle time [75] [76] Perceived time and not actual clock time should be used for the evaluation of whether or not people will accept the transfers.

Functional design of lines: High capacity lines are usually independent lines. Independent networks need efficient transfer and feeder services. Heavy investment is made throughout the world to increase speed and reduce distance; it is proven that design speed is sensitive to distance [77] [78].

The high-speed railway line is the optimum solution to the case study.There is a huge road network, especially in Beijing. But due to problems such as traffic congestion, traffic jams, unhealthy air, higher co_2 content in the air, and many other environmental issues, the city seeks relief from all these problems [42], This is the right time for the country to step up its sustainable development. To connect Beijing with "Xiongan", the city needs to have a regional fast speed railway line, which provides transportation between the two cities in less than 60 minutes [79] [80]. Switzerland provides a model of how this can be done [81].

To analyze the 50 km radius of XiongAn a satellite map was examined as shown in figure 8. The analysis shows that 75% of the study area falls below the 1-22 meter elevation category whereas roughly 80% of slope falls into the category of 0-5%. The Land use/ Land cover classified map derived from Landsat-8 dataset reveals 62% of the area falls under Urban/settlement/roads categories whereas 37% area falls under vegetation (forest/agriculture/urban greenery) and contains one percent of water in the study area.



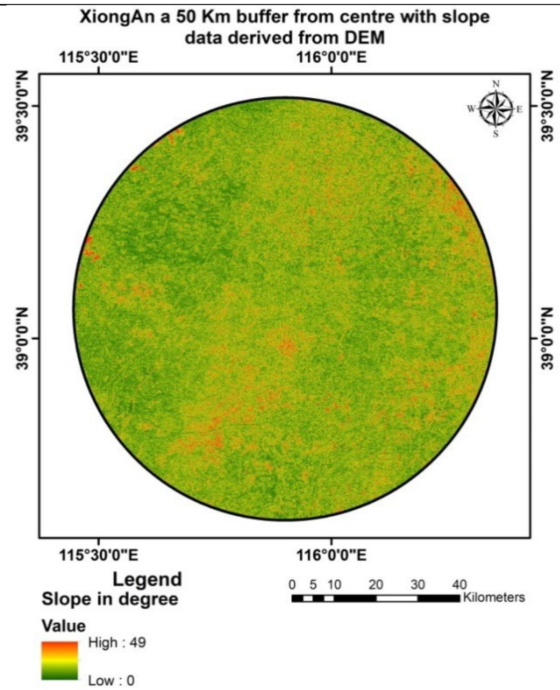


Figure 6, XiongAn Satellite images

Step 2: Defining Criteria and Prioritization Route Using Multi Criteria Method

The variants of transportation between two big cities are evaluated according to the following criteria:

- F1: Cost of travel. This criterion shows the cost of the trip for passengers (ticket price or price of fuel consumption and maintenance of vehicles when road transport is used).
- F2: Travel time. This includes the time for transportation and change of transport from Beijing to XiongAn.
- F3: Type of infrastructure. This factor shows the category of railway lines and roads. For the railway lines that means high speed railway or conventional railway, for road transport that means category of road (motorway or railways)
- F4: Connections. This criterion presents the possibilities of connecting with another mode of transport.
- F5: Comfort. This shows the convenience of the trip.
- F6: Reliability. This criterion takes into account compliance with the transport timetable, and lack of congestion on highways.
- F7: Safety (Minimum risk of accidents)
- F8: Accessibility. This criterion takes into account the possibilities of passengers obtaining the appropriate mode of transport with convenient connections in transport terminals.
- F9: Type of terminal connection. This criterion presents the type of connection (as shown in figure 5).

- F10: Environmentally friendly transport. This means transport with minimal environmental pollution and noise impacts.

In this research five routes and different transport modes connection between Beijing and XiongAn are investigated, taking into account the results of ArcGIS analysis:

- V1: Existing intercity railway line. There is no direct railway line existing in the study area; the nearest line is in Baoding.
- V2: Metro and new railway line
- V3: Motorway-1 Beijing to XiongAn
- V4: Motorway-2 Beijing to XiongAn
- V5: Motorway-3 Beijing to XiongAn

The existing railway intercity line from Beijing West station passes through rural areas. This line is not specifically connected according to GIS Analysics and online Beijing traffic data. Variants with Motorway 1, 2 and 3 (V3; V4; V5) have overall weak connection because they follow the ring road, which is not integrated. The existing railway line (V1) has good integration with other types of transport - Bus, Road transport and Subway. Table 1 presents the characteristics of the various options for transportation between Beijing and XiongAn.

Table 1.Characteristics of variants

	Variant	Length, km	Type of way	Time, h	Accessibility	Connection with another type of transport
V1	Existing intercity railway line	157	railway	3h, 30 minute-4hour	no specific connection	Bus and Subway, Road
V2	New line	105	Metro, railway (High-speed Line)	Should be less than 1 hour.	Metro + new railway line; connections in metro station	Subway Stations
V3	Motorway-1	125	Trunk road +Motorway	1 hour, 48 minute	6th Ring Road+ Motorway	Overall weak connection
V4	Motorway-2	167	Trunk road +Motorway	2 hour 8 minute	6th Ring Road+ Motorway	Overall weak connection
V5	Motorway-3	160	Trunk road +Motorway	2 hour 24 minute	6th Ring Road+ Motorway	Overall weak connection

The present study uses the AHP methodology to determine what weight should be given to each criterion and to estimate the alternatives. Super Decision software is used. Fig.9 presents the structure of the model. A hierarchical decision model has a goal, criteria that are evaluated for their importance to the goal and alternatives that are evaluated for the level of preferences with respect to each criterion. The highest level of the hierarchy is the overall goal: to determine the best connection between Beijing and XiongAn. Under the overall goal, the second level represents ten criteria affecting transport selection. The alternatives for transportation are on the third level.

Pairwise comparison is the process of comparing the relative importance of two criteria with respect to another element (for example, the goal) in the level above to establish priorities for the elements being compared. In this research a group of experts gave an overall score on the scale of Saaty. Table 2 shows the prioritization matrix and the weight given to each criterion by AHP method. The value of consistency ratio (CI=0,097) is less than 0,1. According to equation 4, (Appendix) which means that the expert's assessments are adequate.

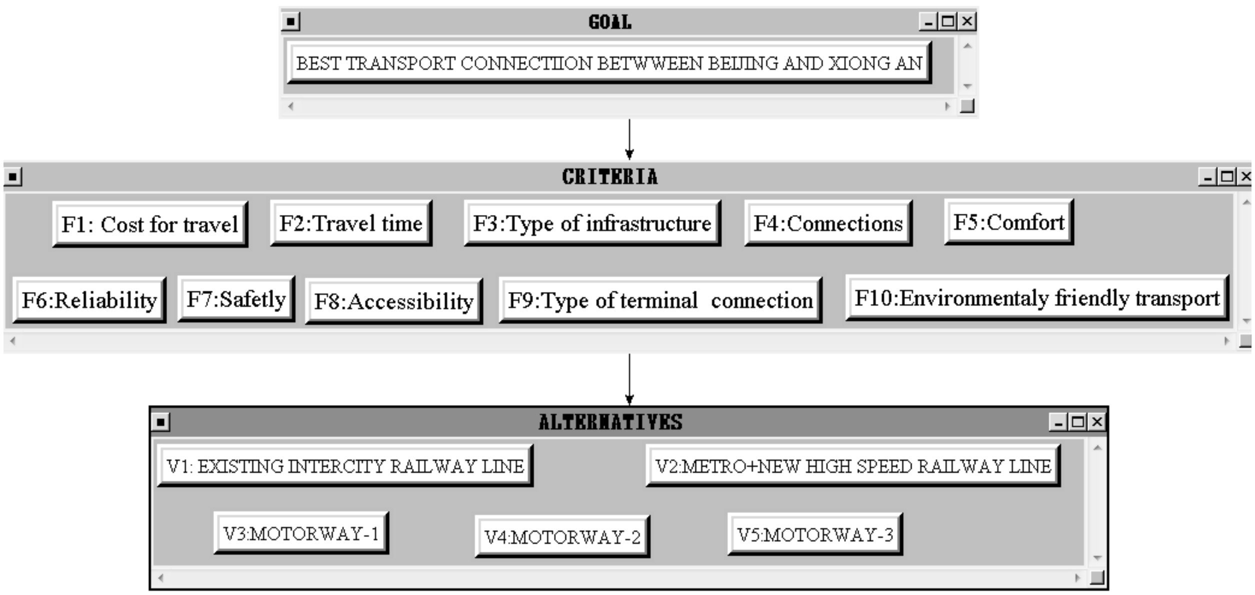


Figure 7, AHP hierarchical model for goals, criteria and alternatives for the Study Area

Table 2, Prioritization matrix of criteria and weights

Criteria	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	Weight
F1: Cost for travel	1	1/2	3	3	2	1	1	4	4	2	0,15
F2: Travel time	2	1	5	3	3	1	1	2	2	2	0,16
F3: Type of infrastructure	1/3	1/5	1	1/3	1/3	1/4	1/4	1/3	1/3	1/3	0,03
F4: Connections	1/3	1/3	3	1	1/3	1/3	1/4	3	3	1/2	0,08
F5: Comfort	1/2	1/3	3	3	1	1/5	1/5	1/3	3	1/2	0,07
F6: Reliability	1	1	4	3	5	1	1/2	1/2	3	1	0,13
F7:Safety	1	1	4	2	5	2	1	2	2	1	0,15
F8:Accessibility	1/4	1/2	3	1/3	3	2	1/2	1	3	1	0,10
F9:Type of terminal connection	1/4	1/2	3	1/3	1/3	1/3	1/2	1/3	1	1	0,04
F10:Environmentaly friendly transport	1/2	1/2	3	2	2	1	1	1	1	1	0,10
CI= 0.097											

It is found that factors affecting prioritization of alternatives includes travel time (0,16), cost of travel (0,15), safety (0,15), reliability (0,13), accessibility (0,10) and environmental protection (0,10) as shown in Fig. 8.

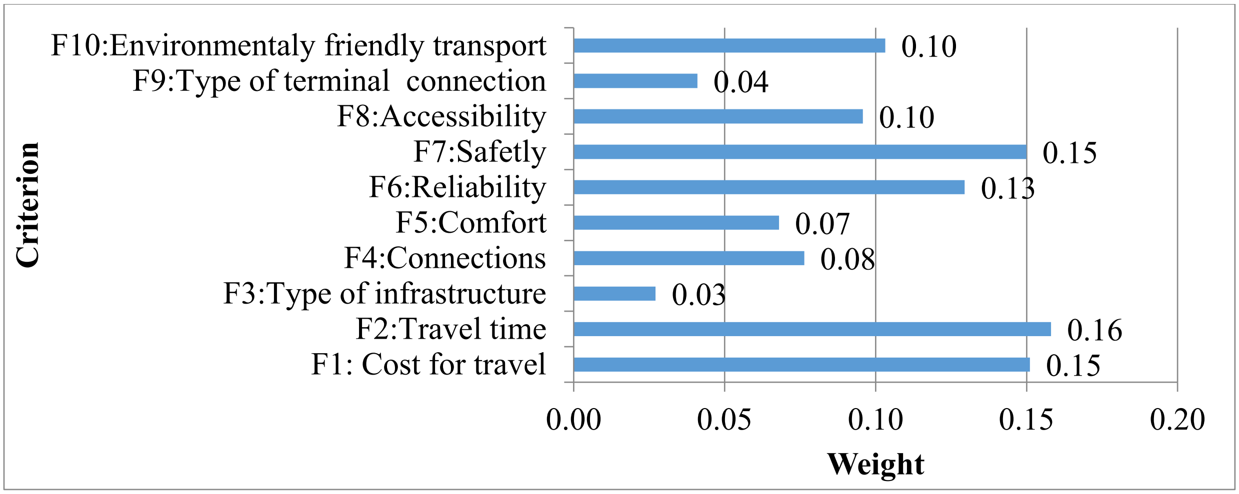


Figure 8, Weights of criteria

Table 3, presents the important intensity levels for evaluating the alternatives. They are rated as excellent, good, above average, average and below average by the level of influence of the criteria. Table 4 shows the evaluation of alternatives by each of criteria. The assessment is made by using intensity levels.

Table 3, five intensity levels and their corresponding values

Super Decisions Ratings	Excellent	Good	Above Average	Average	Below Average	Score
Excellent	1	2	3	4	5	0,42
Good	1/2	1	2	3	4	0,26
Above Average	1/3	1/2	1	2	3	0,16
Average	1/4	1/3	1/2	1	2	0,10
Below Average	1/5	1/4	1/3	1/2	1	0,06

Table 4, Ratings for alternatives

Alternatives	Criteria										Weight
	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	
V1:	Average	Below Average	Good	Above Average	Good	Good	Good	AA	Good	Good	0,17
V2:	Average	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Et	0,27
V3:	Good	Good	Above Average	Good	Good	Good	AA	Good	Good	Below Average	0,21
V4:	Good	Above Average	Above Average	Good	Average	Above Average	Above Average	Good	Above Average	Below Average	0,18

V5:	Good	Above Average	Above Average	Good	Average	Above Average	Above Average	Good	Above Average	Below Average	0,18

Fig.9 shows the prioritization of alternatives and priorities. The highest priority is the option of a connection between Beijing and XiongAn with a new railway high-speed line.

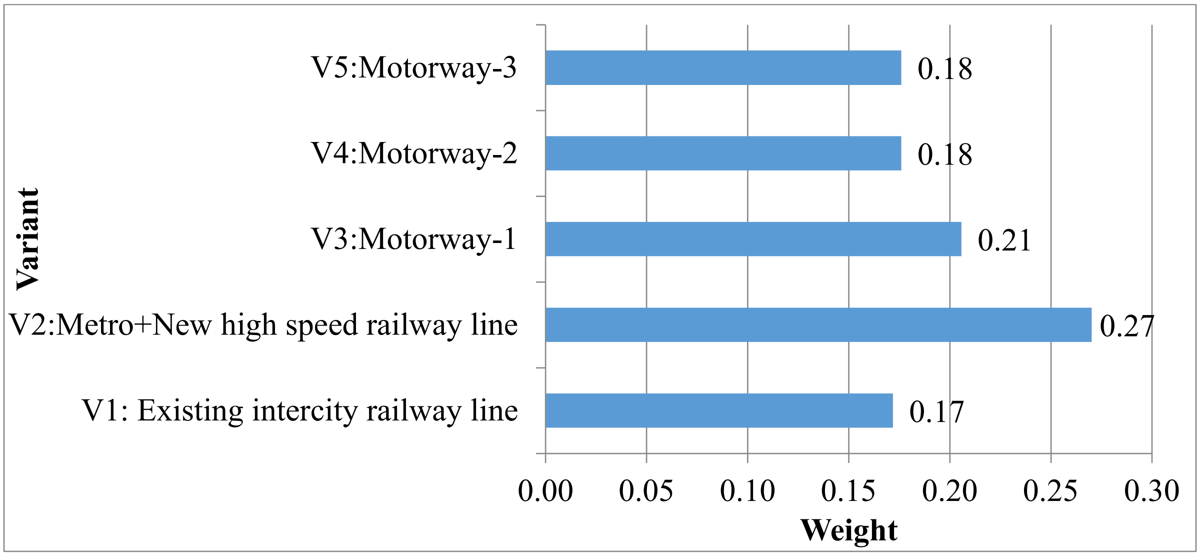


Figure 9, Priorities of alternatives

The sensitivity analysis was also carried out to create the various scenarios based on the priority of the selection criteria. Graphical Sensitivity Analysis enables the researcher to adjust priorities to see the effect of changes in judgments on the overall ranking of decision alternatives. The priority ranges from 0.0 to 1.0 on the x-axis. The assessment is carried out as by increasing and decreasing one of the seven criteria, keeping the others proportionally the same. Moving the dotted line and dragging can give different scenarios of projection changes for the alternatives. Figure 10 gives an example for criterion F1 of graphical sensitivity analysis. It shows the upper limit of AHP score whereby the optimal solution is retained.

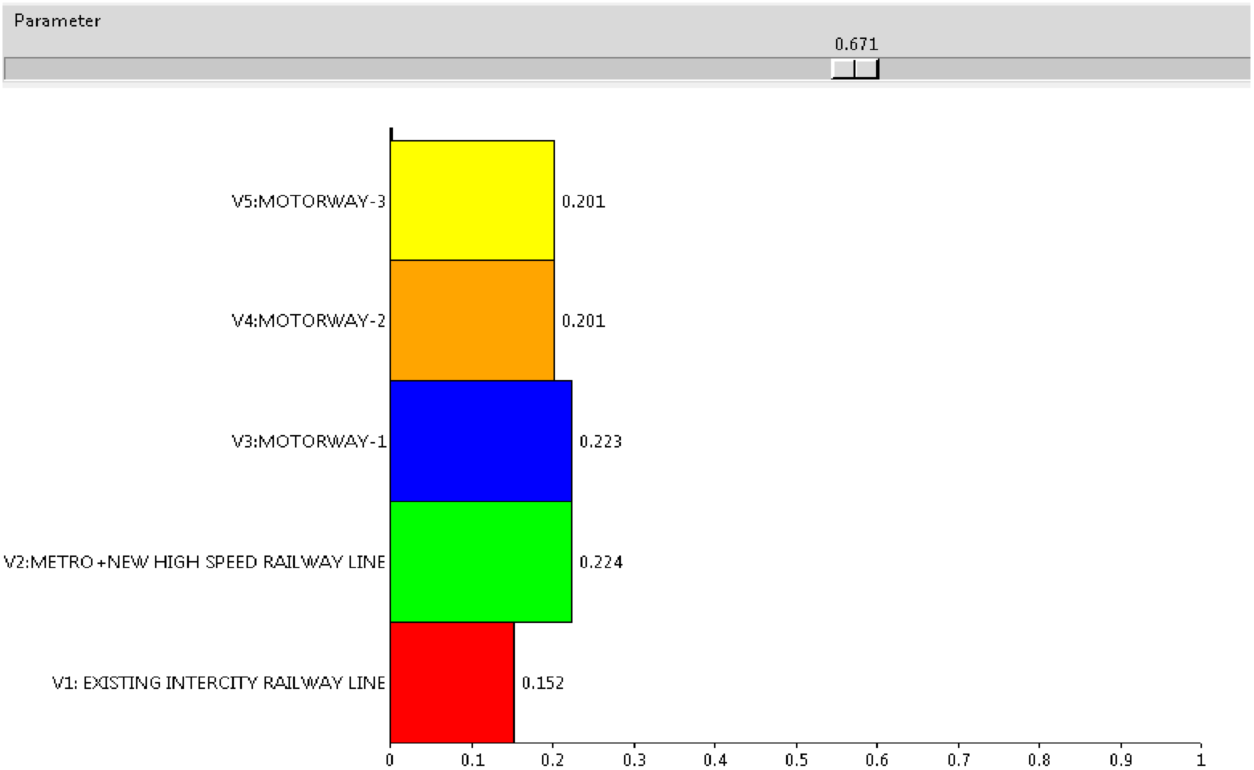


Figure 10, Graphical Sensitivity Analysis for criterion F1

The sensitivity analysis is made for all indicators. The results show that alternative 2 largely retains its position as the best scheme. For the best option, the stability intervals for priority ranges for criteria are F1 (0-0.67%), for all others criteria (0-100%).

Conclusion

The paper presents a multi criteria based transportation planning for satellite towns of the growing cities. The methodology incorporated analytic hierarchy process to evaluate various criteria from a set of alternative options among which best decision was made for the study area. Based on the analysis a railway high line is proposed for the study area. The selection criteria based on cost for travel, travel time, type of infrastructure, connections, comfort, reliability, safety, accessibility, type of terminal connection and environmental friendly transport was evaluated using analytic hierarchy process tool. It was found that travel time, cost of travel, safety, reliability, accessibility and environment mainly responsible criterion for selecting best alternative. The sensitivity analysis also supported the selection of high railway line with metro line to cope with transportation demand of the study area. The methodology developed can be used for similar cities by varying the selection criteria factors based on the priorities of the requirements.

The study suggests that application of GIS and Analytic hierarchy process allow to make best decision for transport planning from available different options. The results of this study demonstrate that the combination of both methods can serve of a decision support system for the route selection. The proposed methodology can be used in research on transport connections and for other cities.

Contribution of Authors: All authors contributed equally in the preparation of this manuscript and declare no conflict of interest.

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Appendix:

Table 5: Saaty's scale for pairwise comparison.

Intensely of importance	Definition
1	Equal importance
3	Moderate importance of one factor over another
5	Strong or essential importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Values for intermediate comparison

The result of the pairwise comparison of n criteria can be summarized in an (n, n) evaluation matrix in which every element a_{ij} ($i, j = 1, \dots, n$), which serves to determine the weights of the criteria.

The matrix elements have the following relationships:

$$a_{ii} = 1; \quad a_{ij} \neq 0; \quad a_{ji} = 1/a_{ij} \qquad (1)$$

The second step in the AHP procedure is to normalize the matrix. The relative weights are given by the normalized right eigenvector ($W = \{w_1,.., w_n\}^T$) associated with the largest eigenvalue ($\lambda_{\max}$) of the square matrix A providing the weighting values for all decision elements. The largest eigenvalue ($\lambda_{\max}$) can be calculated using the following equation:

$$AW = \lambda_{\max}.W \qquad (2)$$

$$\lambda_{\max} = \sum_{i=1}^{n}\left[\left(\sum_{j=1}^{n} a_{ij}\right).W_i\right] \qquad (3)$$

The third step calculates the consistency ratio and checks its value.

The consistency ratio is found in the following formula:

$$CR = \frac{CI}{RI} \leq 0,1 \qquad (4)$$

where: CI is the consistency index; RI is a random index. The random matrix is given by Saaty, [8] as shown in table 2.

Tab 6, Random Consistency Index (RI)

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

The consistency index is:

$$CI = \frac{\lambda_{\max} - n}{n-1} \qquad (5)$$

The largest eigenvalue $\lambda_{\max}$ is the maximum eigenvalue of the priority matrix, n is the number of elements in the matrix. Generally, if the CR is less than 0.10, the consistency of the decision-maker is considered satisfactory. But if CR exceeds 0.10, some revisions of judgments may be required. In order to control the results of the methods, the consistency ratio (CR) is used to estimate directly the consistency of pairwise comparisons.