Transportation Planning through GIS and Multicriteria Analysis

Case Study of Beijing and XiongAn

Abstract

Rapid urban population growth demands ongoing research to address transportation challenges. This study focuses on developing a transportation model between Beijing and the future city of XiongAn to enhance connectivity, reduce travel time, and increase capacity. Using GIS and the Analytic Hierarchy Process (AHP), various transportation options—including existing railways, new high-speed rail, and motorways—were evaluated based on criteria like travel time, cost, safety, and environmental impact. The analysis concluded that building a new high-speed railway line is the most effective solution to meet future demands.

Introduction

Urban and economic growth heavily rely on effective transportation planning, which involves forecasting future needs and analyzing current travel patterns. Despite advancements, planners face challenges such as environmental concerns, integration with land use, and increasing demand. Issues like poor data, weak models, lack of transparency, and limited integration among transport modes particularly affect developing countries. These challenges hinder the effectiveness and appeal of transit systems, making sustainable and efficient planning a long-term but essential goal.

China leads globally in high-speed rail capacity, reflecting its efforts to address transportation demands amid rapid urbanization.

Introduction

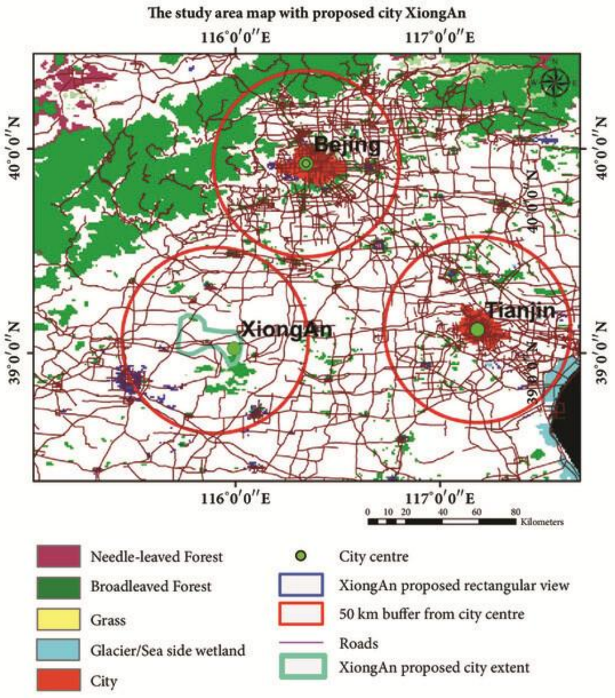
The review highlights the growing need for reliable, efficient, and environmentally sustainable transit systems, particularly in cities like Beijing facing congestion and pollution. Rail transport proves to be less polluting and more efficient than road-based transport. Road network expansion often leads to environmental degradation and urban challenges such as traffic congestion and resource inefficiency. The use of Geographic Information Systems (GIS) and multicriteria analysis (MCA) has become central in modern transport planning, helping planners evaluate multiple factors like cost, travel time, accessibility, environmental impact, and land use. The paper proposes an integrated methodology using GIS and MCA to design efficient transport models between large cities and their satellites, aiming to improve connectivity, optimize routes, and support sustainable urban development.

Methodological Approach

The study adopts a two-step methodological approach: **first, identifying possible routes between cities using Geographic Information Systems (GIS) and route analysis**; **second, evaluating and prioritizing these routes using the Analytic Hierarchy Process (AHP), a multicriteria decision-making method.** AHP assigns weights to different criteria and ranks route alternatives based on their scores. It relies on model structuring, rating development, and priority synthesis, using pairwise comparisons according to Saaty's scale.

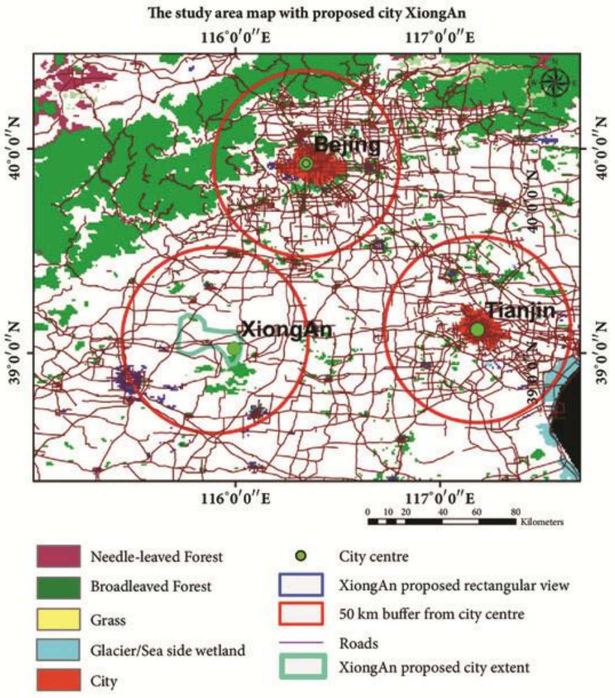
Case Study

This case study focuses on establishing a transportation connection between Beijing and the newly planned satellite city, XiongAn, located in Hebei province. The project aims to relieve Beijing's population pressure and bridge the economic development gap between Beijing, Tianjin, and Hebei. XiongAn is strategically positioned to form an economic triangle (Jing-Jin-Ji) that will boost regional growth, job opportunities, and urban integration.



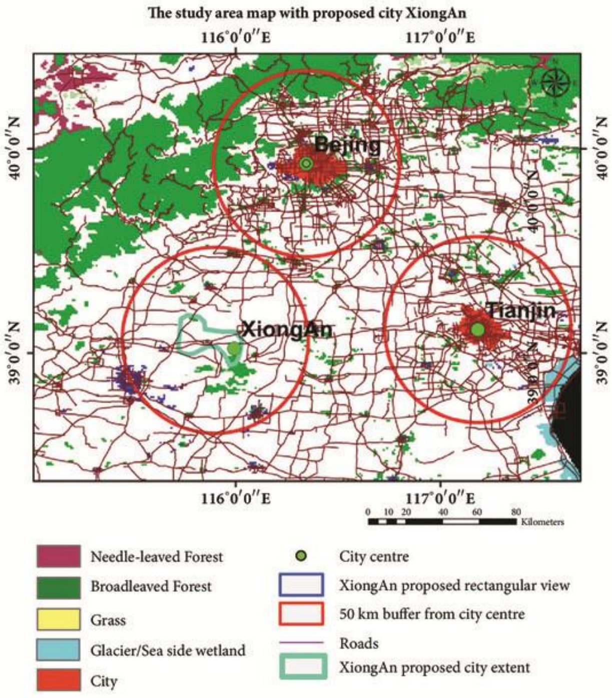
Case Study

With urbanization at its peak in China, the development of XiongAn—initially covering 100 km² with future expansion up to 2000 km²—seeks to address the “urban illness” of overcrowded megacities like Beijing.



Case Study

The map illustrates the spatial context of the proposed city of XiongAn and its relation to Beijing and Tianjin, forming the core of the Jing-Jin-Ji economic triangle. The red circles indicate a 50 km buffer from each city center, highlighting potential zones of influence and connectivity. XiongAn is strategically positioned to balance development between the overpopulated capital, Beijing, and the coastal city of Tianjin. The overlay of roads, forest types, and urban areas helps planners visualize land use and ecological constraints, supporting informed decisions in sustainable urban planning and transportation development.



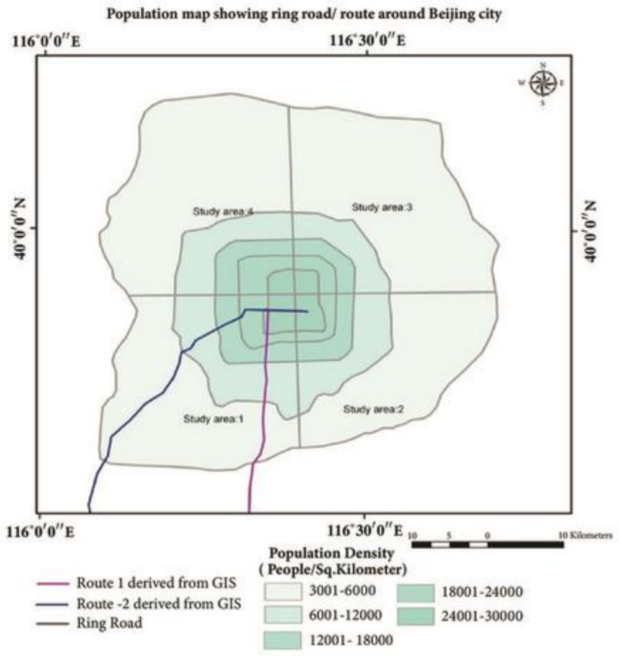
1st Step : identifying possible routes

In Step 1 of the methodology, the study identifies transportation routes between Beijing and XiongAn using GIS and road network analysis. Based on China's "Urban Road Engineering Design Code," roads are classified into four types, varying by speed and capacity.

Road Type	Description
High-speed urban roads	High-speed roads with a design speed of **100–120 km/h** and typically **4 lanes**.
Major trunk roads	Major trunk roads **connecting city districts**, **with 4 or more lanes** in each direction and **40–60 km/h** speed.
Secondary roads	Secondary roads **with 2 to 4 lanes** and a design speed of **30–50 km/h**.
branch roads	branch roads **with 2 lanes** and a speed range of **20–40 km/h**.

1st Step : identifying possible routes

GIS analysis reveals that the only feasible direct connection to XiongAn is via motorway. Within a 50 km buffer zone around Beijing, three potential routes were analyzed: one is 125 km, another 167 km, and a third via Tianjin is 196 km. Estimated travel time for all routes exceeds two hours, While expressways offer high-speed segments (100 km/h), much of the travel involves trunk and secondary roads near residential areas, reducing overall speed due to frequent intersections and lower speed limits.

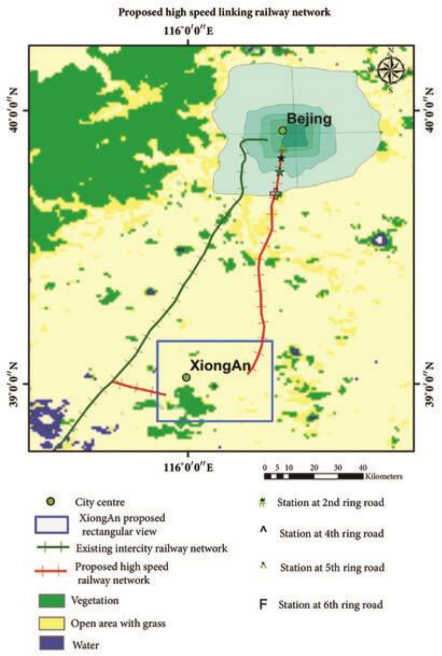


1st Step : identifying possible routes

The study recommends constructing a high-speed radial railway line between Beijing and XiongAn to improve connectivity, reduce travel time, relieve congestion on highways, and promote sustainable development. The current travel time from central Beijing to the edge of the subway network is over 85 minutes for only 26 km, indicating inefficiency. The proposed solution involves a high-speed rail that covers the 130 km distance in under an hour, making daily commuting viable.

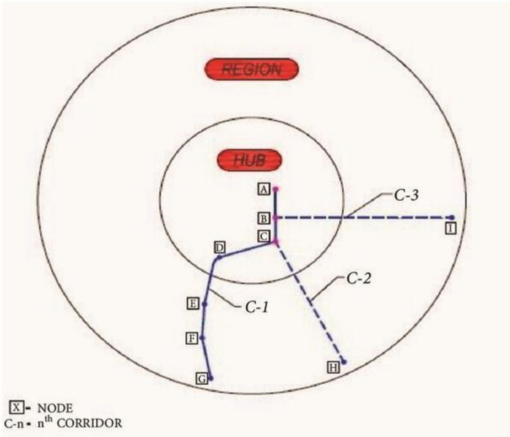
1st Step : identifying possible routes

The new line would have stations at the 2nd, 4th, 5th, and 6th ring roads in Beijing, integrating with existing subway and bus lines to ensure smooth urban-suburban connectivity. This system supports future urban expansion and meets rising transportation demands while addressing environmental concerns such as congestion and pollution.



1st Step : identifying possible routes

A proposed distributed terminal network model for Beijing aims to improve access to public transportation, reduce congestion, and enhance accessibility at central terminals by introducing multiple access nodes along major corridors.

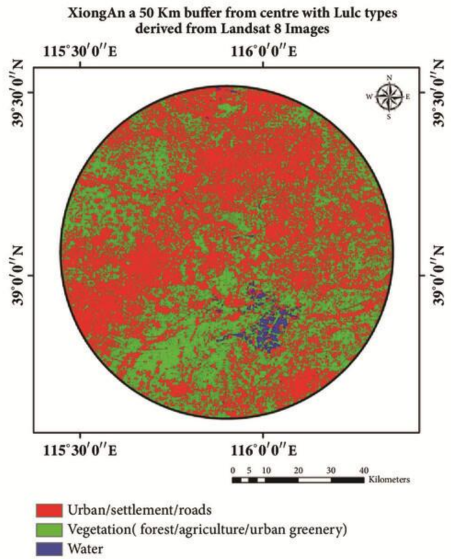


1st Step : identifying possible routes

The land suitability analysis for infrastructure development around XiongAn (within a 50 km buffer zone) is based on several geospatial datasets:

Land Use/Land Cover (LULC):

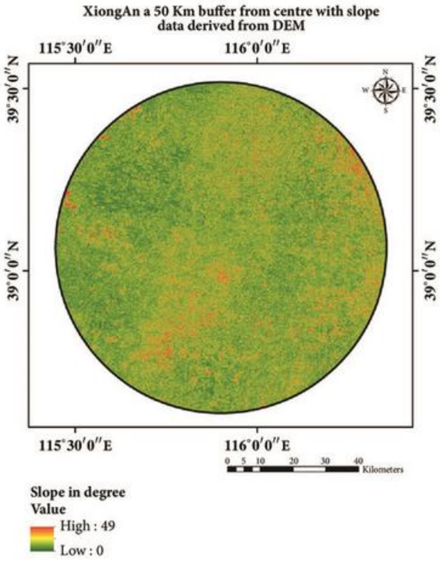
- 62% urban areas
- 37% vegetation
- 1% water.



1st Step : identifying possible routes

Slope :

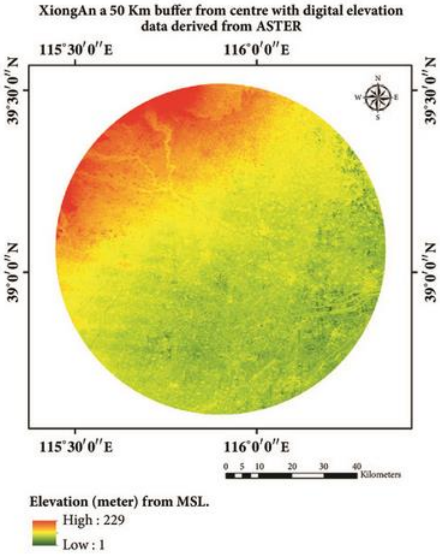
- 80% of the area has gentle slopes (0–5°) that suitable for infrastructure development



1st Step : identifying possible routes

Elevation :

Most of the region has a low to moderate elevation (ranging from 1 to 229 meters), with higher elevations in the northwestern section. This generally supports stable engineering and construction efforts for transit development, especially in southern and southeastern zones where lower elevation prevails



2ed Step : defining criteria and prioritization route

The criteria between two cities are evaluated as following:

F1: **Cost of travel**: This criterion describes the cost of the trip for passengers (ticket price or price of fuel consumption 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.

2ed Step : defining criteria and prioritization route

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: **Level of safety**.

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.

2ed Step : defining criteria and prioritization route

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 XiongA

V4: Motorway 2 Beijing to XiongAn

V5: Motorway 3 Beijing to XiongAn

2ed Step : defining criteria and prioritization route

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

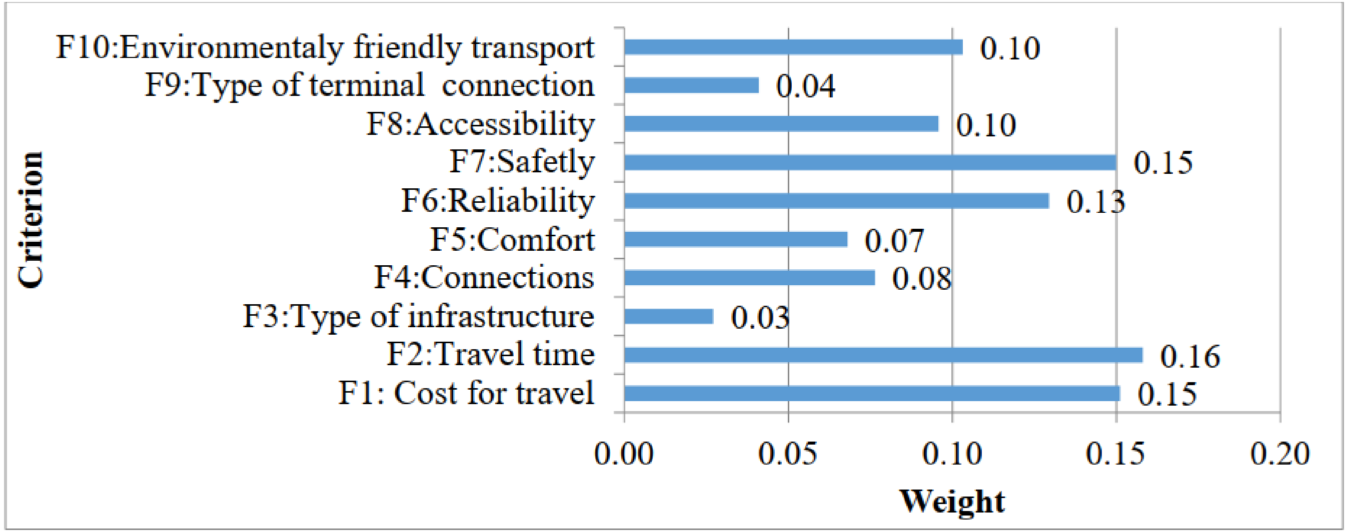
2^{ed} Step : defining criteria and prioritization route

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											

2ed Step : defining criteria and prioritization route

Weights of criteria



2ed Step : defining criteria and prioritization route

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

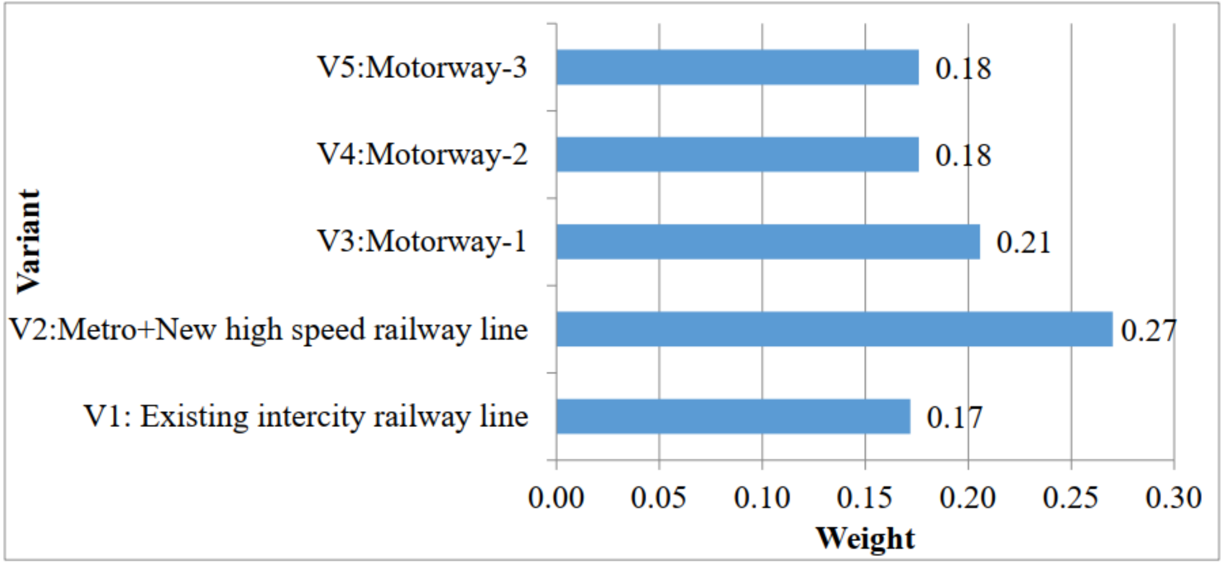
2^{ed} Step : defining criteria and prioritization route

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

2ed Step : defining criteria and prioritization route

Priorities of alternatives



2ed Step : defining criteria and prioritization route

The **Metro + New High-Speed Railway Line (V2)** scored the highest (0.27) due to better travel time, connectivity, and environmental benefits. Sensitivity analysis further confirmed the robustness of this option.

The (V2) is the optimal, sustainable, and scalable solution for connecting Beijing and XiongAn. The low elevation and gentle slopes in most of the XiongAn buffer zone support infrastructure deployment with minimal topographic challenges.

Conclusion

This study developed a multicriteria transportation planning approach using the Analytic Hierarchy Process (AHP) and GIS to determine the best transport connection for satellite towns like XiongAn. Among several alternatives, a high-speed railway line integrated with metro was identified as the optimal solution. Key criteria influencing the decision included travel time, cost, safety, reliability, accessibility, and environmental impact. Sensitivity analysis confirmed the robustness of this choice. The proposed methodology provides a flexible, scalable framework that can be applied to other cities, enabling informed and efficient transport planning decisions.

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