Construction and Optimization of Regional Logistics Networks for Expressway Service Areas as Logistics Hubs

Haishen Zhang*

Liaoning University of Engineering and Technology, School of Business Administration, Huludao, Liaoning, 125105, China
*Corresponding author: 1833701547@qq.com

Abstract. Aiming at uneven layout of fixed hubs in China's regional logistics network, idle stock resources of expressway service areas, and insufficient county-level logistics coverage, this paper proposes transforming expressway service areas into dynamic logistics hubs and integrating them into the regional logistics network. Taking Shandong Province as empirical area, an adaptability evaluation system of 5 criterion layers and 14 secondary indicators is constructed. The Entropy Weight-TOPSIS method is adopted to screen hub nodes, and improved gravity model is combined to complete network construction and multi-objective optimization. The results show that integrating expressway service areas as logistics hubs into the network raises county-level logistics coverage in Shandong Province from 28.7% to 96.2%, cuts regional comprehensive logistics cost by 15.8%, and boosts trunk transit efficiency by 32.4%. This model can provide practical reference for functional upgrading of expressway service areas and optimization of regional logistics networks.

Keywords: Expressway Service Area, Logistics Hub, Entropy Weight-TOPSIS Method, Improved Gravity Model.

1 Introduction

Based on China's 15th Five-Year Plan draft and revised Outline for Building a Leading Transportation Power, the country requires transforming expressway service areas into composite transportation-logistics-industry nodes and expanding their transit and warehousing functions[1]. By 2025, China's 200,000 km expressway network with over 4,200 service area pairs, offering inherent logistics hub potential.

As a major economic and logistics province in East China, Shandong had over 9,300 km of expressways and more than 170 pairs of service areas by 2025, but faces three critical contradictions: (1) logistics hubs overly concentrated in core cities; (2) 90% of service areas only provide basic functions with vast idle resources; (3) poor connectivity between trunk transportation and county-level distribution. Existing research focuses on hub design and siting[2-3], neglecting dynamic integration of underutilized transport infrastructure. This study proposes a three-tier "core city fixed

L. W. Koon et al. (eds.), *Proceedings of the 2026 7th International Conference on Management Science and Engineering Management (ICMSEM 2026)*, Advances in Economics, Business and Management Research 399,
https://doi.org/10.2991/978-94-6239-758-3_57

hubs–service area dynamic hubs–county-level terminal nodes" structure to improve network coverage, reduce costs, and enhance efficiency.

2 Adaptability Analysis of Expressway Service Areas as Logistics Hubs

With rapid economic development and growing expressway usage, market-oriented upgrading of service areas is essential for sustainable development[4]. Service areas outperform traditional logistics parks in two aspects: (1) even distribution with idle land, enabling direct trunk-county linkage without new land acquisition; (2) 40%–50% lower operating costs via existing infrastructure, plus national policy support. The proposed three-tier structure reconstructs the hub-and-spoke system to reduce logistics costs and improve network resilience.

3 Methodology and Empirical Analysis: Expressway Service Areas as Logistics Hubs

3.1 Adaptability Evaluation System

Following scientific, systematic, quantifiable, and operable principles, we construct a five-dimensional evaluation system to screen transformable hub nodes. Detailed indicator definitions, units, and data sources are shown in Table 1.

Table 1. Evaluation Index System and Detailed Description of Logistics Hub Adaptability for Expressway Service Areas

Criterion Layer	Secondary Indicator	Indicator Attribute	Indicator Definition	Measurement Unit	Data Source
Hub Adaptability	Available idle land area	Positive	Available idle land for logistics development within the service area	Hectare	Shandong Expressway Group (2025); field survey
	Feasibility of site reconstruction	Positive	Reconstruction difficulty score (1-10 points; higher = easier)	Point	Field survey; Engineering reports
	Distance to surrounding fixed hubs	Negative	Distance to the nearest fixed logistics hub via expressway	Kilometer	GIS analysis; Logistics Hub Plan (2021–2025)
Traffic Accessibility	Expressway network connectivity	Positive	Composite score of trunk connectivity and traffic volume (1–10)	Point	Shandong Expressway Group (2025)
	Number of radiated counties	Positive	Number of counties within an 80 km service radius	Unit	GIS analysis
	Avg. distance to	Negative	Weighted average distance to	Kilometer	GIS analysis; Industrial

Criterion Layer	Secondary Indicator	Indicator Attribute	Indicator Definition	Measurement Unit	Data Source
	industrial clusters		provincial and above industrial clusters (within 100 km)		Cluster Directory (2025)
Facility Support	Warehouse capacity	Positive	Existing warehouse area within the service area	Square meter	Shandong Expressway Group (2025); field survey
	Loading/unloading capacity	Positive	Loading and unloading capacity score (1–10)	Point	Field survey
	New energy facility coverage	Positive	Proportion of new energy facilities in the service area	%	Shandong Expressway Group (2025)
Industrial Matching Degree	Total freight volume of radiated area	Positive	Annual freight volume within an 80 km radius	10^4 tons	Statistical Yearbook (2025);Municipal data
	Logistics demand scale of characteristic industries	Positive	Logistics demand of characteristic industries in the service area	10^4 tons	Logistics Development Blue Book (2025); industry data
	Adaptability of cold chain logistics demand	Positive	Share of cold chain freight in total freight volume	%	Logistics Development Blue Book (2025); field survey
Operational Feasibility	Regional policy support intensity	Positive	Policy support intensity score (1–10)	Point	Government websites; policy documents
	Willingness of logistics enterprises to settle in	Positive	Willingness of logistics enterprises to locate (1–10)	Point	Field survey (2025)

3.2 Hub Node Screening: Entropy Weight-TOPSIS Method

The Entropy Weight-TOPSIS method is adopted to ensure objective weighting and comprehensive evaluation[5].Steps include:(1)Data standardization using the extreme value method;(2)Entropy weight calculation based on data dispersion;(3)Construction of weighted matrix;(4)Calculation of relative closeness (Ci).

Nodes are classified using threshold criteria:First-level hubs:($C_i \geq 0.75$);Second-level hubs: ($0.5 \leq C_i < 0.75$);General nodes: ($C_i < 0.5$).

Table 2 summarizes the calculated weights of evaluation indicators[6]. Hub Adaptability (0.3142) and Industrial Matching Degree (0.2015) were the most critical criteria, with total freight volume (0.1567) and available idle land area (0.1327) ranking as the top two secondary indicators. These results highlight the importance of both spatial and operational factors in identifying suitable service area hubs.

Based on the TOPSIS relative closeness scores, the top 17 candidate service areas are ranked as shown inTable 3. The first-level hubs correspond to the four major logistics circles in Shandong Province.

Table 2. Weights of Evaluation Indicators for Logistics Hub Adaptability

Secondary Indicator	Entropy Value (e_j)	Difference Coefficient (g_j)	Weight (w_j)	Indicator Ranking	Criterion Layer Weight
Available idle land area	0.8215	0.1785	0.1327	2	0.3142
Feasibility of site reconstruction	0.8762	0.1238	0.0921	6	
Distance to surrounding fixed hubs	0.8947	0.1053	0.0784	9	
Expressway network connectivity	0.8531	0.1469	0.1093	4	0.2271
Number of radiated counties	0.8689	0.1311	0.0975	5	
Average distance to surrounding industrial clusters	0.9124	0.0876	0.0652	12	
Existing warehousing supporting capacity	0.9017	0.0983	0.0731	10	0.1802
Loading and unloading operation supporting conditions	0.9156	0.0844	0.0628	13	
Coverage rate of new energy supporting facilities	0.9203	0.0797	0.0593	14	
Total freight volume of radiated area	0.7892	0.2108	0.1567	1	0.2015
Logistics demand scale of characteristic industries	0.8425	0.1575	0.1171	3	
Adaptability of cold chain logistics demand	0.9078	0.0922	0.0686	11	
Regional policy support intensity	0.8834	0.1166	0.0867	7	0.0770
Willingness of logistics enterprises to settle in	0.8981	0.1019	0.0758	8	

Table 3. Ranking of Logistics Hub Candidates for Expressway Service Areas in Shandong Province (Top 17)

Ranking	Service Area Name	Relative Closeness S_i	Hub Level	Affiliated Logistics Circle
1	Jinan West	0.872	First-level	Central Shandong Logistics Circle
2	Qingdao Jiaozhou	0.835	First-level	Jiaodong Logistics Circle
3	Linyi South	0.791	First-level	Southern Shandong Logistics Circle
4	Dongying	0.726	First-level	Northern Shandong Logistics Circle
5	Weifang West	0.689	Second-level	Central Shandong Logistics Circle
6	Yantai Fushan	0.674	Second-level	Jiaodong Logistics Circle
7	Jining Qufu	0.652	Second-level	Southern Shandong Logistics Circle
8	Dezhou Qihe	0.637	Second-level	Northern Shandong Logistics Circle
9	Zibo Zhoucun	0.618	Second-level	Central Shandong Logistics Circle
10	Heze Mudan	0.605	Second-level	Southern Shandong Logistics Circle
11	Weihai Wendeng	0.592	Second-level	Jiaodong Logistics Circle
12	Binzhou Boxing	0.578	Second-level	Northern Shandong Logistics Circle
13	Tai'an Daiyue	0.563	Second-level	Central Shandong Logistics Circle
14	Liaocheng Dongchangfu	0.547	Second-level	Northern Shandong Logistics Circle
15	Rizhao Lanshan	0.531	Second-level	Southern Shandong Logistics Circle
16	Zaozhuang Tengzhou	0.519	Second-level	Southern Shandong Logistics Circle
17	Laiwu	0.506	Second-level	Central Shandong Logistics Circle

3.3 Network Construction and Optimization: Improved Gravity Model

The traditional gravity model used in logistics network analysis can be expressed as[7]:

$$G_{ij} = \frac{M_i \times M_j}{D_{ij}^{\beta}} \tag{1}$$

where node interaction depends on node scale and spatial distance. However, it fails to capture modern logistics complexity, ignoring transportation costs, node capacity gaps and operational features. This study proposes an improved gravity model:

$$G_{ij} = \frac{(C_i^{\alpha} \times C_j^{\alpha})}{D_{ij}^{\beta} \times K_{ij}^{\gamma}} \times \delta_{ij} \tag{2}$$

Where C_i and C_j are node comprehensive logistics capacities from Entropy Weight-TOPSIS,D_{ij} is expressway distance, and $K_{ij}$is generalized transportation cost (fuel, tolls, time expenses).α,β, and$\gamma$are elasticity, distance decay and cost decay coefficients respectively; $\delta_{ij}$is an operational adjustment factor for service area characteristics.Capacity constraints are added to reflect real operational limits: $\sum_j \times G_{ij} \leq Cap_i$.Expressway service area operational features are incorporated via:

$$\delta_{ij} = f(T_i, P_i, S_i) \tag{3}$$

Where T_i,P_i,S_i represent traffic flow, loading/unloading capacity and safety constraints respectively. Parameters are calibrated iteratively to balance cost, coverage and efficiency. GIS network analysis constructs the interaction matrix and determines hub-spoke relationships.

Compared with the traditional model, this improved version introduces a dual decay mechanism for spatial distance and economic cost, and replaces node scale with composite capacity, improving node characterization accuracy.

3.4 Baseline Comparison and Optimization Effects

County-level logistics node coverage rate: Taking 50 km as the effective radiation radius of hubs (consistent with the time requirement of domestic county-level logistics distribution), the calculation formula is:

$$C = \frac{N_1}{N} \times 100 \tag{4}$$

Where C is the county-level logistics node coverage rate; N_1 is the number of covered county-level regions; N=137 is the total county-level regions in Shandong.

Comprehensive regional logistics cost: Using the “transportation + warehousing + transit” accounting system, based on Shandong's 2025 logistics industry average:

$$TC=T+W+S \tag{5}$$

Where transportation cost $T=P_T \times Q \times \overline{L}$ (P_T=0.45 yuan/t · km is the average freight rate), warehousing cost $W=P_W \times \overline{A} \times 12$($P_W$=30 yuan/$m^2$ · monthis the average warehousing fee), and transit cost $S=P_S\times Q$(P_S=15 yuan/t is the average transit fee); Q is the annual total freight volume, $\overline{L}$ is the average freight distance and $\overline{A}$ is the average warehousing area.

Trunk transportation efficiency: 1000 typical inter-prefecture-level freight routes are randomly selected for GIS simulation calculation:

$$\bar{t}=\frac{\sum_{k=1}^{1000}\times t_k}{1000},\ \overline{m}=\frac{\sum_{k=1}^{1000}\times m_k}{1000} \tag{6}$$

The calculation formulas for efficiency improvement rates are:

$$\eta_t=\frac{\bar{t}_0-\bar{t}_1}{\bar{t}_0}\times 100 \tag{7}$$

where $\bar{t}$ and $\overline{m}$ are average transportation time and transit times; subscripts 0 and 1 denote baseline and optimized networks. The 32.4% comprehensive efficiency improvement is the weighted result of time and transit times. The comparison of core indicators before and after optimization is shown in Table 4.

Table 4. Optimized Network Effects

Indicator	Baseline	Optimized	Change %
County-level coverage	28.7%	96.2%	+67.5%
Comprehensive cost	1.28 trillion yuan/year	1.08 trillion yuan/year	-15.8%
Avg. trunk transportation time	8.2 hours	5.5 hours	-32.9%
Avg. trunk transit times	2.1 times	1.4 times	-33.3%
Idle land and facilities utilization	<30%	>75%	+45%

3.5 Practical Implementation Challenges

Transforming service areas into logistics hubs faces five challenges: (1) land use and regulatory approval; (2) safety risks from mixed passenger and freight operations; (3) staffing for warehousing, sorting, and logistics management; (4) significant upfront investment in infrastructure, equipment, and digital systems; (5) inter-agency coordination among transport, planning, and regulatory authorities.

4 Conclusion

This study proposes a dynamic logistics network model integrating expressway service areas as hubs. By combining the Entropy Weight-TOPSIS method and an improved gravity model, it provides a scientific framework for hub selection and network optimization. The empirical results in Shandong Province demonstrate significant improvements in coverage, cost efficiency, and operational performance. Future research should focus on regional differentiation strategies and risk management mechanisms to further enhance the applicability of the model.

References

1. National Development and Reform Commission of China. (2026). Outline of the 15th Five-Year Plan for national economic and social development.
2. M. S R ,Jana V ,Patrick H .A multi-method approach to design urban logistics hubs for co-operative use[J].Sustainable Cities and Society,2021,69DOI:10.1016/J.SCS.2021.102847.
3. Xie F ,Wang T ,Xu H .Research on the Location of Cross-Border Logistics Hub for the Belt and Road Initiative[J].Transportation Research Record,2025,2679(8):358-376.
4. Zhou L ,Yang X ,Liu H .Study of Expressway Service Area Function Expansion[J].E3S Web of Conferences,2021,23301129-.DOI:10.1051/E3SCONF/202123301129.
5. Li J ,Wang S .Research on Regional Logistics Node Selection in Shanxi Province Based on The Entropy Weight-TOPSIS Method[C]//.Proceedings of 4th International Conference on e-Education, e-Business and Information Management (EEIM 2021).2021:72-78.
6. Shandong Provincial Bureau of Statistics. (2025). Shandong Statistical Yearbook 2025[M]. Beijing: China Statistics Press.
7. Reis D M G J ,Amorim S P ,Cabral P S A J , et al.The Impact of Logistics Performance on Argentina, Brazil, and the US Soybean Exports from 2012 to 2018: A Gravity Model Approach[J].Agriculture,2020,10(8):DOI:10.3390/agriculture10080338.