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Analyzing and Optimizing the Cargo Gathering Network Structure of the Chengyu China-Europe Railway Express

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Abstract

As a crucial component of the Belt and Road Initiative, the China-Europe Railway Express (Chengyu Express) plays a vital role in enhancing Eurasian trade connectivity. This study employs complex network theory, entropy weighting method, and social network analysis to model and analyze the regional freight network structure within the Cheng-Yu economic circle. Using data from 12 cities including Chengdu, Chongqing, and surrounding regions, the research evaluates logistics industry development levels and identifies spatial connection patterns through gravity modeling. Findings reveal that core cities (Chengdu and Chongqing) dominate the network with strong logistics connections, while secondary cities exhibit varying development levels. The study identifies five key cargo consolidation nodes—Chengdu, Chongqing, Suining, Deyang. The research contributes to transportation network optimization theory and provides practical solutions for enhancing the operational efficiency of China-Europe freight services, supporting regional economic integration and logistics competitiveness.

Keywords

China-Europe Railway Express; Low-carbon transport; Cargo network; Complex network theory

Introduction

The China-Europe Railway Express (CRE) serves as a pivotal component of China's Belt and Road Initiative, with the Chengyu Express representing a critical segment that provides direct freight services from Sichuan and Chongqing to Europe. The Chengyu Express has significantly alleviated pressure on coastal ports, mitigated logistics channel risks, and enhanced the openness of western China's economy.

Despite its operational success, the Chengyu Express faces several persistent challenges. Cities beyond the core hubs of Chengdu and Chongqing—such as Deyang, Guangyuan, and other secondary nodes—experience considerably lower train frequencies, typically operating only 1-2 trains per month or less. This disparity in service frequency is compounded by scattered cargo

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sources, which lead to suboptimal container loading rates, prolonged cargo assembly times, and ultimately reduced operational efficiency. These operational bottlenecks not only limit the Chengyu Express's overall efficiency but also constrain the Cheng-Yu region's competitiveness within international logistics networks.

The operational efficiency of the CRE has shown continuous improvement through various optimization strategies. Recent advancements include enhanced on-time rates and transport speeds achieved through optimized operational schemes and consolidation center management, leading to increased loading rates and reduced transit times (Liu and Meng, 2024). The launch of the Chengyu Express has further promoted foreign trade and economic development in the Cheng-Yu region, facilitating industrial upgrading and regional economic integration (He et al., 2022).
Previous research has contributed significantly to logistics network optimization. Camur et al. (2024) developed an optimization framework for efficient logistics operations through transportation mode optimization and shipment consolidation. Aliakbari et al. (2022) enhanced logistics network reliability and robustness by building evaluation models and optimization strategies to ensure efficient network operation during emergencies. The Gravity Model has been widely applied in logistics evaluation and optimization research, while Wang et al. (2018) employed the entropy weight method to study logistics industry development levels in CRE node cities. Social Network Analysis (SNA) has been extensively used in logistics network structural analysis and optimization (Wolfe, 1997), with Mu et al. (2022) applying SNA to study synergistic effects within the Cheng-Yu regional logistics network.

While existing studies have achieved notable results in optimizing the overall network structure and improving logistics efficiency of the CRE, research focusing specifically on regional logistics networks remains insufficient. As a vital component of the CRE, optimizing the Cheng-Yu cargo collection network holds significant importance for enhancing logistics efficiency and economic competitiveness. This study aims to address this research gap by systematically analyzing the existing urban network structure of the Chengyu Express to identify optimal cargo assembly points and improve operational efficiency.

The primary objectives of this research are to: (1) evaluate the logistics industry development levels across Cheng-Yu cities using a comprehensive indicator system; (2) analyze spatial logistics connections through gravity modeling; (3) identify key cargo consolidation nodes that can optimize network efficiency; and (4) provide practical recommendations for enhancing the Chengyu Express's operational performance. By addressing these objectives, this study not only provides a scientific basis for Chengyu Express operations but also offers new perspectives and methodologies for optimizing regional logistics network structures.

Methodology

This study employs an integrated research framework combining entropy weighting method, gravity model, and social network analysis.

Research data were primarily sourced from the 2022 China City Statistical Yearbook, Sichuan Statistical Yearbook, and Chongqing Statistical Yearbook, covering logistics development indicators for 16 major cities in the Chengdu-Chongqing region, as Figure 1.

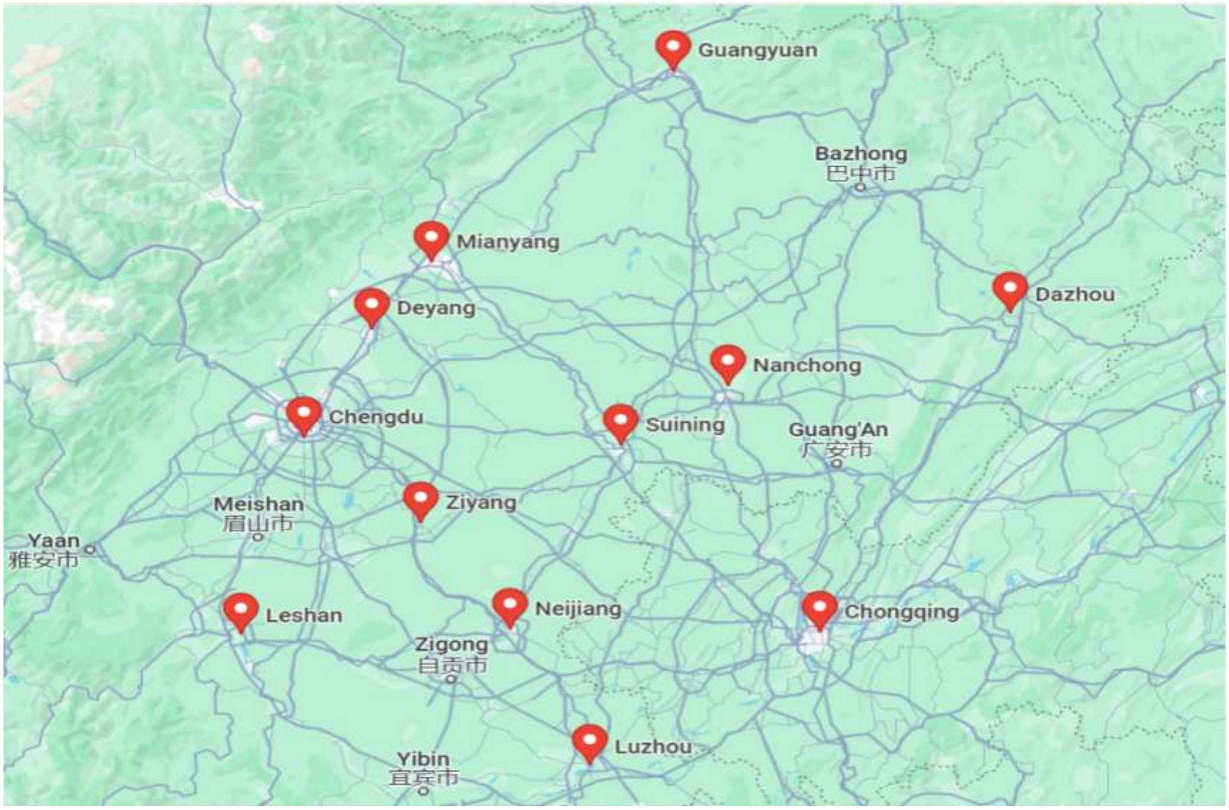


Figure 1: Locations of cities operating Cheng-yu Express

Based on logistics industry development level evaluation, an assessment system comprising 4 first-level indicators and 12 second-level indicators was established (Table 1). Specific indicators include: total freight volume, road freight volume, railway freight volume, civilian vehicle ownership, postal business volume, express delivery volume, total import and export value, actual utilized foreign capital, total retail sales of consumer goods, tertiary industry added value, railway operational mileage, and expressway density.

Table 1: Evaluation System for Logistics Industry Development Level of Cheng-yu Express Cities

Target layer	Criterion layer	Indicator layer
Development level of logistics industry	Scale of logistics industry	Number of employees in the logistics industry
		Freight volume
		Cargo turnover
	Infrastructure of logistics industry	Fixed assets value
		Total road mileage
		Operational mileage of railways
		Number of logistics parks
		GDP

	Level of economic development	Total retail sales of consumer goods
		Volume of import and export

Entropy Weighting Calculation: First, raw data were standardized:

$$Y_{ij} = \frac{X_{ij} - \min_j \{X_{ij}\}}{\max_j \{X_{ij}\} - \min_j \{X_{ij}\}}$$

Then the entropy value for the j-th indicator was calculated: $e_j = -k\sum_{i=1}^{m} p_{ij} \ln p_{ij}$.

Finally, weights were computed: $\mathrm{w}_j = \frac{1-\mathrm{e}_j}{\sum_{j-1}^{n}(1-\mathrm{e}_j)}$.

Gravity model are detailed as follows:

$$M_{ij} = k_{ij}\frac{Z_i Z_j}{{t_{ij}}^2}$$

In the model, M_{ij} measures the spatial logistics gravity between city i and city j; Z_i and Z_j represent the development levels of the logistics industry in the respective cities. The term t_{ij} denotes the time distance between city i and city j, indicating specifically the time taken for railway freight transportation between these two cities. This study utilizes the actual GDP proportions to define the coefficient of attraction, with the formula given by $k_{ij} = GDP_i / (GDP_i + GDP_j)$. The attraction from city j to city i is calculated using a similar approach.

Results and Discussion

The Gravity method was used to calculate the development level of the logistics industry in cities served by the Chengyu Express, as shown in Table 2. The results showed significant variation in the development level of the logistics industry among the cities served by Cheng-Yu trains. Among these cities, Chongqing, located at the core of the Yangtze River Economic Belt, had the highest overall logistics industry development level, followed by Chengdu, the capital of Sichuan Province, while the smaller city of Ziyang had the lowest score.

Table 2: Scores of Logistics Development Level in Cheng-Yu Cities

Year /city	2021	2022	average	rank
Chengdu	0.236019	0.238029	0.237024	2
Chongqing	0.507455	0.502820	0.505138	1
Mianyang	0.032650	0.038648	0.035649	6
Deyang	0.025097	0.024744	0.024921	8
Guangyuan	0.011877	0.016217	0.014047	11
Nanchong	0.040564	0.037505	0.039034	4
Suining	0.013948	0.016718	0.015333	10
Dazhou	0.038405	0.046603	0.042504	3
Luzhou	0.038233	0.034037	0.036135	5
Neijiang	0.017266	0.018103	0.017684	9

Ziyang	0.009550	0.008787	0.009168	12
Leshan	0.027296	0.025526	0.026411	7

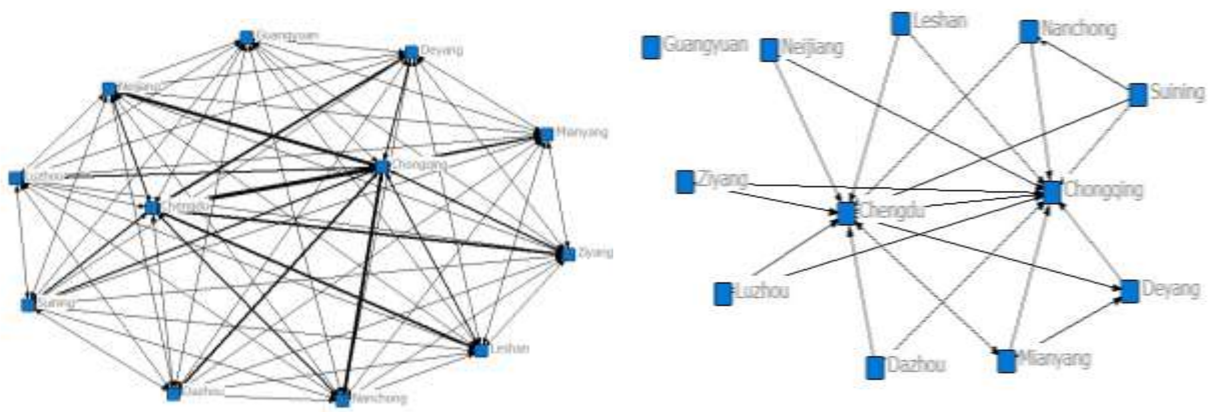
The logistics connection intensity value between Chengdu and Chongqing cities is obtained through the gravity model, as shown in Table 3. Judging from the total value of the overall link strength, Chongqing (21.5097) and Chengdu (19.5449) occupy a dominant position in the logistics link between Chengdu and Chongqing cities.

Table 3 presents the analysis of spatial logistics connections of cities served by the Cheng-yu Express

	Cd	Cq	My	Dy	Gy	Nc	Sn	Dz	Lz	Nj	Zy	Ls
Cd		5.2511	0.3861	0.5382	0.0083	0.1546	0.0555	0.0447	0.0691	0.1423	0.0940	0.2404
Cq	4.3195		0.1308	0.0755	0.0140	0.2765	0.0989	0.1936	0.1467	0.1614	0.0178	0.0601
My	1.8984	1.0143		0.5873	0.0137	0.0712	0.0260	0.0249	0.0443	0.0268	0.0156	0.0387
Dy	3.0995	0.9350	0.5066		0.0080	0.0466	0.0224	0.0188	0.0311	0.0290	0.0197	0.0397
Gy	0.1360	0.3297	0.0455	0.0197		0.0591	0.0081	0.0267	0.0115	0.0151	0.0041	0.0101
Nc	1.0656	3.7360	0.1257	0.0530	0.0287		0.2785	0.1570	0.0316	0.0248	0.0079	0.0258
Sn	1.4672	1.0894	0.0503	0.0390	0.0060	0.4269		0.0440	0.0263	0.0349	0.0097	0.0213
Dz	0.4353	2.4427	0.0318	0.0199	0.0079	0.2288	0.0326		0.0197	0.0118	0.0043	0.0143
Lz	0.5620	1.5588	0.0653	0.0330	0.0041	0.0330	0.0142	0.0197		0.0361	0.0118	0.0432
Nj	1.7769	3.6846	0.0531	0.0272	0.0055	0.0393	0.0231	0.0160	0.0591		0.0180	0.0481
Zy	2.4234	0.7989	0.0538	0.0554	0.0043	0.0205	0.0143	0.0098	0.0241	0.0346		0.0340
Ls	2.3611	0.6693	0.0617	0.0504	0.0051	0.0321	0.0165	0.0140	0.0497	0.0367	0.0110	
total	19.544	21.509	1.5107	1.4986	0.1056	1.3885	0.5901	0.5692	0.5130	0.5536	0.2139	0.5759

The data in Table 3 is used to obtain the logistics network structure at the Cheng-yu Express cities by NetDraw, and set the threshold value to the mean value to get Figure 4(a) and (b) . Comparing a and b , it is evident that there are significant differences in the logistics links between the cities of Cheng-Yu.Core hub cities: Chongqing and Chengdu not only have strong connections with other cities, but also significant connections with other high-center cities (such as Nanchong and Neijiang).

The identified core-periphery structure has significant implications for regional logistics efficiency. Chengdu and Chongqing's dominance creates both opportunities and challenges - while they drive economic growth, their overwhelming centrality may lead to network vulnerability and congestion. The presence of weak nodes like Ziyang and Guangyuan substantially reduces overall network resilience and increases transportation costs for peripheral regions.



(a) (b)

Figure 4: Logistics Network Structure of the Cheng-yu Express Cities(a: Threshold is 0; b:Threshold is the average value)

Regarding environmental impact, the concentration of logistics activities in core hubs presents a double-edged sword. While consolidation could potentially reduce carbon emissions through optimized routing and economies of scale, the current imbalanced distribution likely leads to inefficient empty-haul movements and increased fuel consumption in supplying peripheral areas.

Our findings suggest specific actionable strategies: First, establish consolidated logistics corridors between Chengdu-Chongqing and secondary nodes to reduce redundant transportation. Second, develop Ziyang and Guangyuan as specialized logistics gateways for specific commodities to improve network balance. Third, implement green logistics policies that incentivize route optimization and modal shift to rail transport between major hubs.

Conclusion

This study identifies Chengdu and Chongqing as core logistics hubs within a hierarchical network structure in the Chengdu-Chongqing region. The research contributes to logistics optimization by quantifying connection strengths and revealing structural inefficiencies. Limitations include data constraints from 2022 statistics and gravity model assumptions. Future research should incorporate real-time logistics flow data and environmental impact metrics to develop more sustainable network optimization strategies that balance economic efficiency with carbon reduction objectives.

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