A Study on Influencing Factors of Railway Freight Volume Based on Grey Relational Analysis and Decision Support

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Abstract

The aim of this study is to explore the influencing factors of railroad freight volume and their degree of association through gray correlation analysis method to provide decision support for railroad freight management and planning. First, data on railroad freight volume and data on possible influencing factors were collected from 2013 to 2022. Subsequently, gray correlation analysis was used to analyze and calculate the connection between each influencing factor and freight volume, and the degree of association of each factor on freight volume was derived. The results of the study show that among the selected influencing factors, there is a strong correlation between the number of people employed in the railroad transportation industry and the freight volume, and these factors may have an important impact on the volume of railroad freight. Through the analysis in this study, we identified specific influencing factors with high correlation and proposed corresponding improvement measures, such as suggestions for policy adjustment, investment increase or optimal resource allocation for certain factors.

Keywords

Grey Correlation Analysis, Railway Freight Volume, Railway Freight Efficiency

1. Introduction

With the continuous advancement of economic development, the analysis of railway freight volume has become an increasingly important topic in the field of transportation economics and logistics management. Railway freight volume not only reflects the intensity of logistics activities, but also serves as an important indicator of macroeconomic operation, industrial structure adjustment, and regional development strategies. A systematic analysis of freight volume can help to identify long-term trends in freight demand, improve the accuracy of freight forecasting, optimize transportation networks and resource allocation, and provide scientific evidence for the formulation of effective transport strategies. Furthermore, studying the dynamics of freight demand is crucial for enhancing transport efficiency, reducing energy consumption, mitigating environmental impacts, and ultimately promoting sustainable development across the entire economy. [1]

Economic growth typically generates an increasing demand for the movement of goods. As a high-capacity, efficient, and relatively low-cost transport mode, railways possess significant advantages in meeting large-scale freight requirements, especially in resource-intensive and bulk commodity transportation. By employing quantitative analytical methods such as grey relational analysis (GRA), the associations between freight demand and its influencing factors can be more precisely captured. This provides a robust methodological foundation for rational freight planning, investment decision-making, and policy design.

Grey relational analysis of railway freight volume not only offers insights into the forecasting of future freight demand but also assists in identifying structural relationships, optimizing resource allocation, and uncovering potential bottlenecks within the transport system. In addition, GRA contributes to evidence-based policymaking and enterprise-level decision-making by highlighting the key drivers of freight volume variation. [2] The application of this approach therefore holds practical significance for both railway operators and policymakers, as it facilitates a deeper understanding of transport demand evolution and supports the long-term planning of railway development strategies.

When investigating the relationship between railway freight volume and comparative sequences—such as gross domestic product (GDP), railway employment, operational railway mileage, fixed-asset investment, and per capita disposable income of urban residents—grey relational analysis provides a rigorous tool to explore their degree of interdependence. The relationships can be interpreted as follows:

First, GDP reflects the overall scale and development level of a nation's or region's economy. A high degree of correlation between GDP and railway freight volume implies that macroeconomic growth directly drives the expansion of freight demand, consistent with the notion that logistics activities are a barometer of economic vitality. Second, employment in the railway transport sector represents labor input and workforce capacity. A strong association between this indicator and freight volume indicates that human resource allocation within the railway industry significantly influences transport capacity and operational efficiency. [3] Third, operational railway mileage reflects the spatial scale and infrastructural reach of the railway network. A high correlation between mileage and freight volume suggests that network expansion and regional connectivity are vital drivers for increasing freight transport capacity.

In addition, fixed-asset investment represents the intensity of capital input into railway construction and modernization. Its strong association with freight volume underscores the pivotal role of infrastructure investment in shaping transport capacity and fostering long-term growth of the freight sector. Finally, per capita disposable income of urban residents is an indicator of residents' income and consumption capacity. A significant correlation between this variable and railway freight volume suggests that rising income levels, by stimulating industrial output and consumer demand, indirectly promote freight transportation demand.

In summary, conducting a grey relational analysis on railway freight volume and its influencing factors not only deepens the understanding of the intrinsic relationship between economic and transport systems, but also provides theoretical support and practical reference for railway freight demand forecasting, capacity expansion planning, and sustainable development strategies. [4]

2. Research Methods and Data Sources

2.1 Research Methods

Gray correlation analysis is an analytical method used to study uncertain systems, commonly applied when dealing with limited sample data, incomplete information, or high levels of uncertainty. It primarily explores the interrelationships and influence levels among factors by calculating their correlations and determining the extent to which each factor affects system changes. In grey relational analysis, the key lies in selecting appropriate correlation calculation models and effective data preprocessing methods to ensure the accuracy and reliability of analytical results. Simultaneously, results must be interpreted and utilized rationally based on specific problems and analytical objectives to provide scientific grounds for decision-making. [5]The steps of grey relational analysis are as follows:

Step 1: Select the reference sequence X0 = (x01, x02, x03, x04, x05, x06, x07) and the comparison sequence Xi = (xi1, xi2, xi3, xi4, xi5, xi6, xi7), where i = 1, 2, 3, ..., n.

Step 2: Perform dimensionless processing on variables. Common methods include the initial value method and the mean value method. Here, the initial value method is applied to obtain X'i = Xi/xi1 = (x'i1, x'i2, ..., x'in), where i = 0, 1, 2, ..., m.

Step 3: Calculate the difference sequence, maximum difference, and minimum difference.

The difference sequence is: $\Delta_{0i}(k) = \left|x'_0(k) - x'_i(k)\right|, k = 1, 2, \cdots, n$

The maximum defference is: $M = Max_i Max_k \Delta_i(k)$

The minimum difference is: $m = Min_i Min_k \Delta_i(k)$

Step 4: Calculate the correlation coefficient.

$$r\left(x_0(k), x_i(k)\right) = \left(m + \S M\right) / \left(\Delta_{0i}(k) + \S M\right), \S \in (0,1)$$

Where § denotes the discrimination coefficient, typically set to §=0.5

Step 5: Determine the correlation degree.

$$r\left(x_0, x_i\right) = \frac{1}{n}\sum_{ki=1}^{n} r\left(x_0(k), x_i(k)\right); i = 0, 1, 2, \cdots, m$$

Step 6: Analyze results. If r(x0, xi) > r(x0, xj) > r(x0, xk) > ... > r(x0, xz), it indicates xi is superior to xj, xj is superior to xk, and so on. Denote xi > xj > xk > … > xz. Here, xi > xj indicates that factor xi has a higher grey correlation degree with reference sequence x0 than xj. A higher correlation degree signifies a stronger bond between this group of factors and the parent factor. [6]

2.2 Data Sources

The data utilized in this paper are statistical figures from the National Bureau of Statistics covering the period 2013–2022. The reference sequence is railway freight volume (10,000 tons), while the comparison sequences are:

- Gross Domestic Product (100 million yuan)
- Employment in the railway transportation sector (persons)
- Railway operating mileage (10,000 kilometers)
- Fixed-asset investment (excluding rural households) (100 million yuan)
- Per capita disposable income of urban residents (yuan)

3. Grey Relational Analysis

Railway freight volume (10,000 tons), gross domestic product (100 million yuan), railway transportation industry employment (persons), railway operating mileage (10,000 kilometers), fixed-asset investment (excluding rural households) (100 million yuan), and per capita disposable income of urban residents (yuan) are denoted as x0, x1, x2, x3, x4, and x5 respectively. [7]

The aforementioned data were obtained from the National Bureau of Statistics and plotted to generate Table 1.

Table 1. Data Table.

	x0	x1	x2	x3	x4	x5
2013	396697	592963.2	1796382	10.31	297765.7	26467
2014	381334	643563.1	1902500	11.18	338976.4	28844
2015	335801	688858.2	1874448	12.1	369463.2	31195
2016	333186	746395.1	1874131	12.4	396441.5	33616
2017	368865	832035.9	1848032	12.7	421971.8	36396
2018	402631	919281.1	1833800	13.17	446942	39251
2019	438904	986515.2	1915824	13.99	470997.5	42359
2020	455236	1013567	1886517	14.63	484844.8	43834
2021	477372	1149237	1893458	15.07	508796.1	47412
2022	498424	1204724	1866230	15.49	534948.2	49283

The initial value method was applied to the above table to perform dimensionless processing, yielding Table 2. Dimensionless processing is a method of transforming data to eliminate units or dimensions, facilitating comparison and analysis. This process removes differences in units and dimensions between data sets, thereby enhancing the efficiency and accuracy of data analysis.

Table 2. Dimensionless Conversion Table.

	x0	x1	x2	x3	x4	x5
2013	1	1	1	1	1	1
2014	0.961273	1.085334	1.059073	1.084384	1.1384	1.08981
2015	0.846492	1.161722	1.043457	1.173618	1.240785	1.178638
2016	0.8399	1.258755	1.043281	1.202716	1.331387	1.27011
2017	0.929841	1.403183	1.028752	1.231814	1.417127	1.375146
2018	1.014959	1.550317	1.02083	1.277401	1.500986	1.483017
2019	1.106396	1.663704	1.06649	1.356935	1.581772	1.600446
2020	1.147566	1.709325	1.050176	1.419011	1.628276	1.656176
2021	1.203367	1.938125	1.05404	1.461688	1.708713	1.791363
2022	1.256435	2.031701	1.038883	1.502425	1.796541	1.862055

Table 3 was obtained by performing differential sequence calculations on Table 2.

Table 3. Differential List.

	x1	x2	x3	x4	x5
2013	0	0	0	0	0
2014	0.124061	0.0978	0.123111	0.177127	0.128537
2015	0.315229	0.196965	0.327125	0.394293	0.332145
2016	0.418854	0.20338	0.362815	0.491487	0.430209
2017	0.473342	0.098912	0.301973	0.487286	0.445306
2018	0.535359	0.005871	0.262442	0.486027	0.468058
2019	0.557308	0.039906	0.250539	0.475376	0.49405
2020	0.561759	0.09739	0.271445	0.48071	0.50861
2021	0.734759	0.149327	0.258321	0.505346	0.587996
2022	0.775266	0.217552	0.24599	0.540106	0.60562
MAX	0.775266	0.217552	0.362815	0.540106	0.60562
MIN	0	0	0	0	0

After calculating the differential sequence, we obtained the maximum difference MAX = 0.775266 and the minimum difference MIN = 0 between the two poles. With a resolution § = 0.5, the grey correlation coefficients and grey correlation degrees are presented in Table 4.

Table 4. Grey Relational Coefficients and Grey Relational Degrees.

	x1	x2	x3	x4	x5
2013	1	1	1	1	1
2014	0.757548	0.79853	0.758957	0.686367	0.750979
2015	0.551506	0.663076	0.542327	0.495741	0.538545
2016	0.480644	0.655879	0.516535	0.440933	0.47397
2017	0.450225	0.796706	0.562108	0.44305	0.46538
2018	0.419975	0.98508	0.59629	0.443689	0.453006
2019	0.410219	0.906662	0.607412	0.449164	0.439651
2020	0.408296	0.799205	0.588145	0.446405	0.432509
2021	0.345363	0.721903	0.600094	0.43409	0.397316
2022	0.333333	0.640519	0.611773	0.417826	0.390266
Relevance	0.515711	0.796756	0.638364	0.525727	0.534162

Based on the comprehensive analysis of the grey relational coefficients, the relative strength of the influencing factors on railway freight volume can be ranked as follows: Railway Transportation Industry Employment (0.796756) > Railway Operating Mileage (0.638364) > Per Capita Disposable Income of Urban Residents (0.534162) > Fixed Asset Investment (0.525727) > Gross Domestic Product (0.515711). This ordering reveals that employment within the railway transportation industry has the most significant association with freight volume, while GDP exhibits the weakest correlation among the selected indicators. [8]

Although the correlation coefficient of GDP (0.515711) is relatively low, it cannot be ignored in explaining changes in railway freight volume. From one perspective, GDP growth generally stimulates industrial expansion, production activities, and commodity circulation, which in turn generate demand for freight transport, including railways. However, GDP growth also promotes the development of competing transportation modes such as highways, waterways, and pipelines, potentially diverting freight away from rail transport and reducing its relative competitiveness. This dual effect indicates that the influence of GDP on rail freight volume is complex and mediated by multiple structural and institutional factors, such as industrial policy orientation, the relative cost of different transport modes, and the spatial distribution of economic activities.

The coefficient of fixed-asset investment (0.525727), while similarly modest, nonetheless highlights the structural importance of capital formation. Investment in railway infrastructure, including track expansion, modernization of rolling stock, and upgrading of freight terminals, directly enhances rail transport capacity, efficiency, and reliability. On the other hand, fixed-asset investment also drives the growth of other economic sectors and transport infrastructure, which may alter modal competition and indirectly affect rail freight's share in the logistics market. Therefore, the role of fixed-asset investment in promoting rail freight development must be understood in a broader context, including capital allocation efficiency, technology adoption, and the extent to which investments are targeted toward freight-oriented projects rather than passenger-oriented ones.

The coefficient for per capita disposable income of urban residents (0.534162) suggests that income growth exerts a certain, albeit limited, influence on rail freight volume. Rising disposable incomes typically expand consumer demand, particularly for manufactured goods, imported products, and e-commerce-related logistics, which may stimulate demand for transport services. However, this relationship is indirect and mediated by industrial restructuring and supply chain adjustments. For example, higher incomes may promote the use of more flexible and time-sensitive transport modes (e.g., road transport, air cargo), thereby dampening the demand for rail freight. Consequently, the relatively weak correlation underscores that the link between income growth and freight demand is neither linear nor uniform, and is subject to substitution effects across different transport modes.

By contrast, railway operating mileage (0.638364) demonstrates a stronger association with freight volume. The expansion of the rail network creates new transport corridors, improves regional accessibility, and reduces transportation costs, all of which facilitate the growth of freight demand. Furthermore, increased mileage enhances system resilience by diversifying transport routes and alleviating capacity constraints in high-demand corridors. The positive correlation between mileage and freight volume thus reflects the fundamental role of infrastructure availability in shaping transport capacity and service quality.

The most significant factor, employment in the railway transportation industry (0.796756), shows a strong and direct relationship with freight volume. Higher employment levels translate into increased operational capacity, greater service reliability, and improved efficiency in handling freight tasks such as loading, unloading, dispatching, and maintenance. This suggests that the human resource dimension of railway transport remains a critical determinant of its performance, even in the context of gradual automation and digitalization. Conversely, fluctuations in freight volume also feed back into employment levels: when freight volume expands, more personnel are required to sustain operations, whereas a decline in freight demand reduces labor demand and creates pressure on sectoral employment. Moreover, railway freight activities generate significant indirect employment in upstream and downstream industries, including rolling stock manufacturing, infrastructure maintenance, and logistics services. This reciprocal relationship underscores the systemic interdependence between railway freight volume and employment dynamics within the transport sector.

In summary, the analysis demonstrates that macroeconomic indicators such as GDP and per capita income exert only a limited direct influence on railway freight volume, reflecting the fact that freight demand is shaped not solely by aggregate economic activity but also by modal competition, industrial structure, and consumer preferences. By contrast, structural and sector-specific variables—namely railway employment and operational mileage—exhibit stronger correlations, highlighting the importance of both human and infrastructural capacity in supporting freight development. Fixed-asset investment, though important, appears less influential when considered in isolation, suggesting that investment effectiveness and technological innovation may be more decisive than sheer capital input. Taken together, these findings suggest that future policies aimed at enhancing railway freight development should prioritize improving network coverage, strengthening workforce capacity, and increasing the efficiency of investment, while also accounting for the broader competitive environment of multimodal transport.

4. Development Recommendations

4.1 Enhancing Railway Transportation Efficiency

Improving railway transportation efficiency is fundamental to strengthening the competitiveness of rail freight. A first priority is the modernization and upgrading of freight facilities. This includes the optimization of cargo loading and unloading processes, the introduction of advanced cargo handling equipment, and the expansion of freight car loading capacity. [9] Such improvements reduce dwell times, enhance operational efficiency, and lower overall logistics costs. Furthermore, adopting digital technologies—such as intelligent scheduling, big data analysis, and real-time monitoring—can further streamline freight operations and improve system efficiency.

4.2 Expanding Railway Operating Mileage

Extending the length of operational railway lines is crucial for meeting growing freight demand and alleviating network congestion. Strategic measures include strengthening railway construction in key regions such as urban-rural fringe zones, industrial clusters, and port hinterlands, thereby aligning infrastructure expansion with regional and industrial freight flows. Additionally, optimizing railway route planning in accordance with economic development strategies enhances the rational allocation of transport capacity. Improving the accessibility of stations and terminals, as well as expanding the number and coverage of freight distribution centers, further facilitates cargo entry, exit, and transshipment. These measures strengthen the spatial connectivity of the railway network, reduce transport bottlenecks, and enhance freight service quality.

4.3 Strengthening Talent Development

Human resources are an essential pillar of railway transport efficiency. Efforts to strengthen talent development should include cultivating and attracting professionals with expertise in railway operations, logistics management, and intelligent transport technologies. [10] Comprehensive training programs and continuous professional development opportunities should be implemented to improve employees' technical competence and adaptability to technological change. In parallel, vocational training and technical certification systems should be strengthened, encouraging personnel to acquire relevant qualifications and enhancing professional standards across the industry. Moreover, the cultivation of professional ethics and service-oriented mindsets is critical to fostering a workforce capable of supporting sustainable industry development.

4.4 Enhancing Service Quality

Service quality represents a key determinant of railway competitiveness relative to alternative transport modes. Improvements can be achieved through the simplification of service procedures, the provision of convenient loading and unloading facilities, and the establishment of seamless connections with other transport modes. Advancing multimodal transport and logistics distribution enhances the value proposition of rail freight by offering integrated solutions to customers. Expanding collaborative arrangements with logistics enterprises and other carriers further consolidates diverse resources and service offerings, thereby improving reliability and customer satisfaction.

4.5 Strengthening Safety Management

Efficient railway transport must be underpinned by robust safety management systems. Establishing and refining a comprehensive safety supervision framework ensures that safety measures are effectively implemented and regularly monitored. [11] The formulation and enforcement of clear safety regulations, combined with systematic inspections, enable the early identification and mitigation of risks. A proactive approach to safety management not only prevents accidents and operational disruptions but also builds customer confidence in rail freight services.

4.6 Promoting Intermodal Transportation

The promotion of intermodal transportation is a critical pathway to improving overall efficiency and service quality. Strengthening interconnections between railway, road, air, and water transport facilitates seamless transfer, reduces handling costs, and improves transport flexibility. Optimizing the spatial layout of intermodal nodes enhances coverage and accessibility, making the railway system more user-friendly. Furthermore, innovative practices such as logistics information sharing, collaborative distribution, and platform-based coordination improve multimodal resource allocation and operational efficiency. The integration of digital platforms into intermodal systems enhances transparency and enables real-time coordination across different transport modes.

Overall, the above measures collectively contribute to improving the efficiency, reliability, and sustainability of railway freight transport. Modernizing freight facilities, expanding network coverage, strengthening human capital, enhancing service quality, improving safety management, and promoting multimodal integration form a comprehensive strategy for boosting railway competitiveness. These initiatives not only expand the accessibility of railway lines and hubs but also improve logistics efficiency, reduce environmental impacts, and foster regional economic development. Ultimately, strengthening railway freight transport will play an important role in promoting sustainable growth, reducing carbon emissions, alleviating road congestion, and enhancing the international competitiveness of the national transport system.

5. Conclusion

Based on the results of the grey correlation analysis, several key conclusions can be drawn. First, railway operating mileage and employment in the railway transportation sector are identified as the most influential factors affecting railway freight volume. The expansion of railway operating mileage not only increases available transport corridors but also enhances overall transport capacity, thereby creating favorable conditions for sustained freight growth. Similarly, higher levels of employment in the railway transportation sector improve operational efficiency, service reliability, and freight-handling capabilities, which in turn drive freight volume upward.

In contrast, fixed-asset investment, GDP, and per capita disposable income of urban residents demonstrate relatively weaker correlations with railway freight volume. Although these factors are not entirely insignificant, their influence appears to be indirect and mediated by other structural and institutional variables, such as modal competition, industrial restructuring, and consumer demand patterns. This suggests that macroeconomic growth or income improvement alone does not directly translate into proportional increases in rail freight demand.

Overall, the findings highlight that railway freight volume is shaped more significantly by sector-specific variables—namely infrastructure coverage and human resources—than by broader macroeconomic indicators. This underscores the importance of aligning railway development strategies with operational and workforce considerations rather than relying solely on macroeconomic expansion.

Nevertheless, the analysis also indicates that the relationship between these factors and freight volume is dynamic and complex. For example, while fixed-asset investment currently exhibits a weaker direct impact, its long-term role in technological modernization and capacity enhancement should not be underestimated. Similarly, GDP growth and rising household incomes may indirectly influence modal choices and logistics demand patterns over time.

Therefore, while this study provides meaningful insights, it also points to the need for further research. Future studies could employ panel data, econometric models, or system dynamics approaches to better capture causal mechanisms and interaction effects among influencing factors. Additionally, incorporating environmental, technological, and policy-related indicators may yield a more comprehensive understanding of the determinants of railway freight development.

In sum, the grey correlation analysis confirms the central role of railway network expansion and workforce capacity in driving freight volume growth, while also highlighting the nuanced and multi-dimensional nature of the relationship between rail freight and broader economic variables. These findings provide a valuable reference for policymakers and railway enterprises seeking to optimize resource allocation, strengthen sectoral competitiveness, and promote the sustainable development of railway freight transport.

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