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Factor Analysis of Railway Carrying Capacity Coordination Optimization Considering Energy Consumption

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ABSTRACT

High-speed railways, as crucial transportation tools, are characterized by high efficiency, safety, and eco-friendliness, making them an ideal mode of transportation. However, we face increasing energy consumption pressures to achieve better transport services. This paper employs factor analysis to explore improving high-speed railway transport services by adopting resource-saving principles. Railway carrying capacity construction is investigated to better understand its structural features and development trends. Various methods, such as data cleaning, filling, and normalization, are used to obtain more accurate results. Through in-depth analysis, we identify several factors closely related to energy utilization, including train operation speed, urban rail planning, and energy-saving technologies. These measures improve the economic benefits of high-speed railways and contribute to sustainable social development. However, challenges arising from these efforts should be noticed. By combining factor analysis with optimization techniques, reducing energy consumption enhances the railway's cargo-carrying capacity and ensures its long-term sustainability. Future scientific and technological advancements will further explore and apply this approach.

Keywords: Energy Consumption, Railway Carrying Capacity, Coordination Optimization

1. Introduction

As modernization advances, railways have been recognized as the most efficient, reliable, and resource-saving logistics mode. It is not only the infrastructure of modern society but also a powerful management response to changing demands. However, the problem of energy waste is receiving increasing attention [1]. Therefore, how to effectively utilize the advantages of railways has become urgent. To achieve more economical and environmentally friendly railway cargo transportation, we must establish a comprehensive energy-saving mechanism to achieve optimal results at a minimal cost. This paper will adopt various factor analysis techniques to delve into various energy-saving factors to achieve the best overall effect. With technological progress, engineering advancements, and growing consumer travel habits, railway transport is no longer a simple physical means; it must possess a stronger carrying capacity [2] to meet the increasing travel demand in the world today. Moreover, due to global energy shortages and severe environmental conditions, saving resources and protecting the ecology has been widely recognized. With technological development, railway transport efficiency has improved significantly; however, rational utilization has become an urgent issue due to continuous energy consumption. Therefore, research on railway carrying capacity has evolved from traditional single techniques [3], such as transport network transformation, precise train scheduling, and intelligent driving, to more advanced levels. In this study, we will focus on exploring how to improve railway networks to enhance transport efficiency and availability. We will optimize train tracks and station locations and improve train operation to enhance their reliability. Additionally, we will strive to promote train automation to improve passenger safety. Although current research has begun to consider the impact of energy [4], many areas remain unexplored. Specifically, research on effective resource utilization and saving is still in its infancy, and these areas need further strengthening to improve railway operation efficiency effectively. To enhance railway transport efficiency, we must carefully explore achieving the best comprehensive efficiency through rational energy utilization [5]. The goal of this research is to use factor analysis to explore the impact of energy consumption factors on the coordination optimization of railway carrying capacity. Through this study, we can recognize that considering energy consumption factors, decision-makers in the railway transport sector can organize and optimize carrying capacity more effectively, achieving the purpose of energy saving and transport efficiency enhancement.

2. Related Work

Previous research has indicated that for the coordination and optimization of railway carrying capacity, besides considering structural, safety, and reliability factors, the impact of energy consumption must also be fully considered [6]. Therefore, this paper delves into this issue and proposes some practical solutions. An optimized railway transport network is crucial for effectively achieving cargo circulation. To achieve this, scientific track intersection techniques, advanced information systems, intelligent control systems, and various simulation algorithms are employed to finely adjust railway lines, effectively reducing cargo consumption and significantly improving cargo circulation performance. Despite the increasing emphasis on energy in recent years, many issues still still need to be fully recognized. Effective train scheduling is particularly important as it ensures timely cargo delivery and improves transport efficiency. To address this, we have adopted advanced mathematical simulation techniques and algorithms to design train schedules, carefully enhancing cargo transport efficiency. Although recent research has largely overlooked the impact of energy, efficient resource-saving and utilization remain urgent. Resource conservation and utilization help alleviate environmental pressure and improve railways' overall transport efficiency [7]. Railway transport can significantly improve energy utilization efficiency using advanced intelligent energy management technology. For example, optimizing train traction, braking force, and reasonable energy supply can reduce energy consumption and increase carrying capacity [8]. Additionally, these technologies can be combined with other factors to achieve more efficient energy utilization [9]. Despite some research on the coordination and optimization of railway carrying capacity, the impact of energy needs to be addressed. This fact proves that railway energy consumption is a significant issue. To achieve optimal results, we need to enhance carrying capacity and scientifically utilize and conserve resources. To better manage and utilize railway transport, we must carefully explore how to maximize its impact by comprehensively evaluating various factors affecting energy consumption. To achieve this, we will use multiple techniques, including factor analysis and weight allocation, to determine the optimal railway transport strategy. Through systematic research, this study aims to explore a new mode that improves railway transport, ensuring both carrying capacity and effective energy reduction, thereby ensuring the sustainability of railway transport [10].

3. Algorithm Design

Using advanced algorithms is of significant importance for enhancing the performance of the railway transportation control system. These algorithms can accurately identify various factors that influence system performance, provide precise divisions of these factors based on different requirements, and assign corresponding weights to them. We propose a new classification algorithm to better assess the efficiency of railway transportation. This algorithm considers multiple perspectives, such as the operational cycles of trains, distances between stations, cargo weight, and energy usage. We also subject all collected information to preprocessing, such as noise removal, filling in missing data, and eliminating inaccurate information. Before using the algorithm, selecting the most representative and relevant features from the raw data is essential, which can be obtained using statistical techniques, correlation analysis, and other methods. Subsequently, we transform these features into more accurate and effective models through principal component analysis, factor analysis, and other techniques to achieve better classification. To address the significant differences among the data in this study due to varying scales and large variations, we employ min-max normalization, and formula (1) is used to achieve this goal.

$$x_{ik} = \frac{x_{ik} - \min(x_k)}{R_k} \quad (1)$$

By modifying the original data, where Rk is the number of training samples of class Xk having attribute Xik, we can effectively enhance the accuracy and reliability of the model by correctly selecting and using these types of classification algorithms. Considering the specific problem and data, we should choose an appropriate classification algorithm to build the foundational model. The unit market share refers to the share of a generator unit in the entire market, which can be obtained by calculating formula (2).

$$S_{n,t} = \frac{q_{n,t}}{q_t} \times 100\% \quad (2)$$

Where: Sn,t is the unit market share of generator unit n at time t; qn,t is the declared capacity of generator unit n at time t; qt is the total declared capacity in the market at time t. We can construct a predictive model by analyzing the labelled dataset. Improvements in predictive accuracy can be achieved by evaluating these predictions. Through cross-validation and grid search, we can ensure that our model accurately predicts and handles various scenarios. Furthermore, as shown in the figure below, we can use specific formulas to ensure accurate predictions and handling of various scenarios.

$$W_{ge,n,t} = \frac{q_{n,t,ac} - q_{n,t}}{q_{n,t,ac}} \quad (3)$$

Where Wge,n,t represents the holding ratio of generator unit n at time t; qn,t,ac is the available capacity of generator unit n at time t. We use a series of validation sets to check the correctness of the trained classification model, and the evaluation metrics include accuracy, precision, recall, and F1 score. After rigorous inspection and testing, we can deeply understand the model's performance and generalization potential. Carefully designed classification models can effectively assist in the optimization of railway transportation capacity, converting real-time data into effective classification predictions, and allowing precise analysis of influencing factors with reasonable weight allocations, thus achieving the optimal optimization effect of railway transportation capacity. Importantly, the design of the classification algorithm is an iterative process. In practical applications, we may need to adjust and optimize the parameters and models of the algorithm multiple times to enhance classification accuracy and reduce energy consumption. Through data analysis, preprocessing, feature selection, algorithm selection, model training, and validation of large datasets, the design of classification algorithms can effectively address energy consumption issues and significantly improve the railway transportation system's capacity, providing decision-makers with a scientific decision-making basis.

4. Experimental Design and Analysis

Experimental design and analysis are important means to improve railway transportation capacity. It involves considering energy consumption factors and accurately evaluating experimental results to ensure the effectiveness and impact of optimization measures. Therefore, this paper proposes a feasible experimental design and analysis plan to achieve optimal transportation efficiency. Before conducting the experiments, we must clearly define the objectives and hypotheses. For example, our goal may be to reduce railway transportation energy consumption and enhance carrying capacity by modifying parameters such as train speed, loading rate, and composition. We should also consider other factors that significantly impact energy consumption and carrying capacity. With the rapid development of railway transportation, the annual transport volume has been continuously increasing. The annual data, measured in billions of ton-kilometers, shows a steady upward trend, with each year's data consistently growing, as shown in Figure 1.

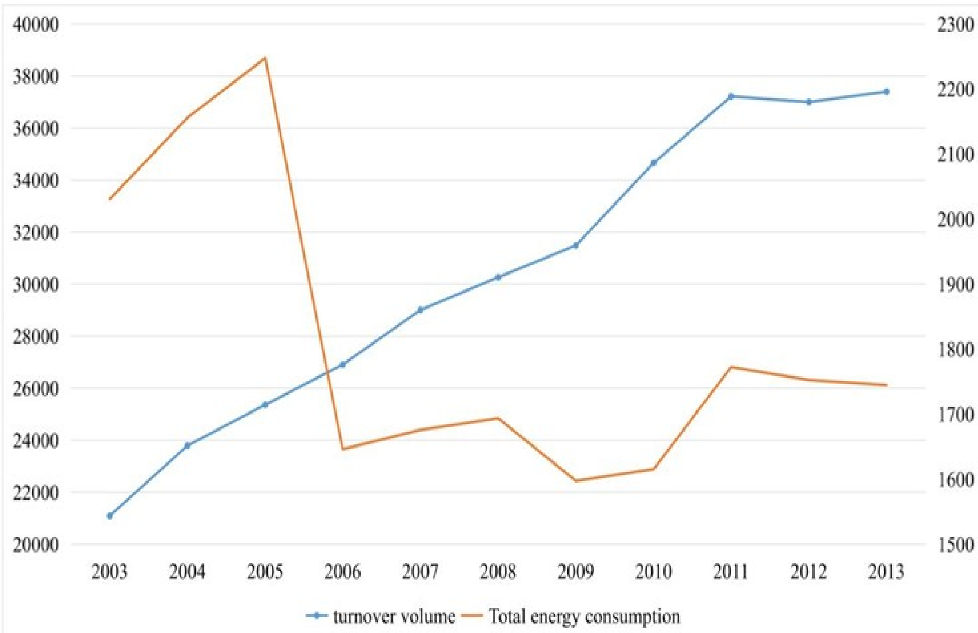

Figure 1. shows the variation curve of the national railway's converted turnover volume and energy consumption total

Based on this assumption, we will consider various possible real factors to evaluate the performance of trains. For instance, we will consider the train's running speed and adjust it to three stages: low, medium, and high. We will also consider factors such as the train's load condition, train composition, fuel efficiency, and maintenance costs. To more accurately assess specific experimental conditions, we must design various experimental methods. These methods include complete randomization, block design, and factorial nesting. To avoid bias, we need to use the same samples in all experimental groups and ensure consistency across all test groups.

Through simulation experiments, we found that when the longitudinal positional stiffness increases from 20 MN/m to 60 MN/m, the vertical, horizontal, axial, suspension coefficients, tilt coefficients, load reduction degree of high-speed freight trains, and the maximum values of horizontal and vertical accelerations of the train body are relatively stable. The variation in longitudinal positional stiffness can significantly reduce the dynamic performance of freight trains, with a reduction of up to 10%.

According to Figure 2, when the vehicle is traveling at 120 km/h, the deviation amount of Y will significantly decrease as the body reaches an extreme height. This decrease may compromise the safety of the outer wheel-rail contact. Therefore, setting the maximum deviation value of Y at this speed, as indicated by Curve 2, will enhance the overall system stability. At a speed

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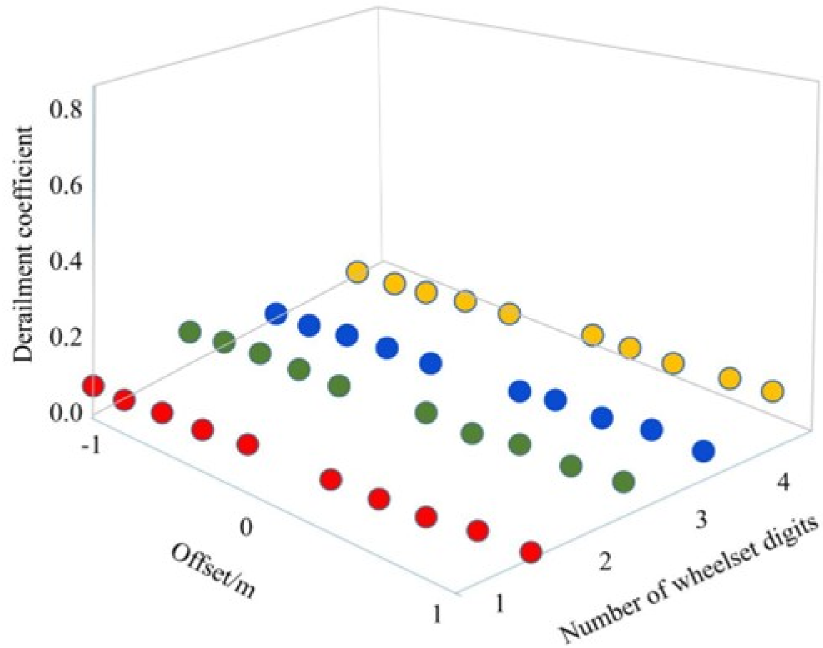

Figure 2. Deviation coefficient of wheelset relative to Y-direction load of cargo

of 200 km/h, the lower position of the freight's centre of gravity results in insufficient contact with the road surface, affecting road safety. Consequently, when the Y-axis has a larger negative deviation range, it should be set at the positive side of Axis 2 and used as the maximum deviation range. Based on the measurements from Curve 2, significant improvements in the Y-direction deviation limitation can be observed when the vehicle is traveling at 120 km/h.

To better understand this improvement, we will adopt experimental analysis, using the improvement of lateral positional stiffness as a reference for evaluating the vehicle's travel distance. According to the experimental results, when the lateral positional stiffness increases from 2 MN/m to 6 MN/m, the maximum variations in wheel-rail vertical force, tilt lateral force, lateral wheel action force, deviation coefficient, overturning coefficient, wheel load reduction rate, and vehicle tilt and vertical acceleration will decrease by 15%. This will contribute to a better understanding of the vehicle's travel characteristics and effectively control its travel distance. In most cases, the lateral positional stiffness does not significantly affect the dynamic performance of the freight train. We will use carefully selected sensors and monitoring systems to collect finer and more reliable data, including the vehicle's energy consumption, operational cycles, cargo unloading volume, cargo distribution, and train composition, to obtain more precise results. By employing statistical methods, we can gather information about the experimental results. Specifically, we will measure each sample's mean, variance, and standard deviation and use Analysis of Variance (ANOVA) to assess their correlation. Through comprehensive research, we have observed that different experimental conditions lead to varying outcomes, determining their contributions to energy consumption and load performance.

From Figure 3, it can be observed that when the freight train is on the straight track, bend 1, and bend 2 sections, its safety index significantly improves, with each index reaching its maximum value. This indicates that even on the lowest track sections, faster speeds of the freight train result in better safety. Simulation tests found that when the vehicle moves along Track 1, whether at low or high speeds, all operational safety indicators are below the expected threshold. However, as the vehicle continues to move along the high track, these indicators gradually decrease until reaching around 325 km/h, which has been confirmed.

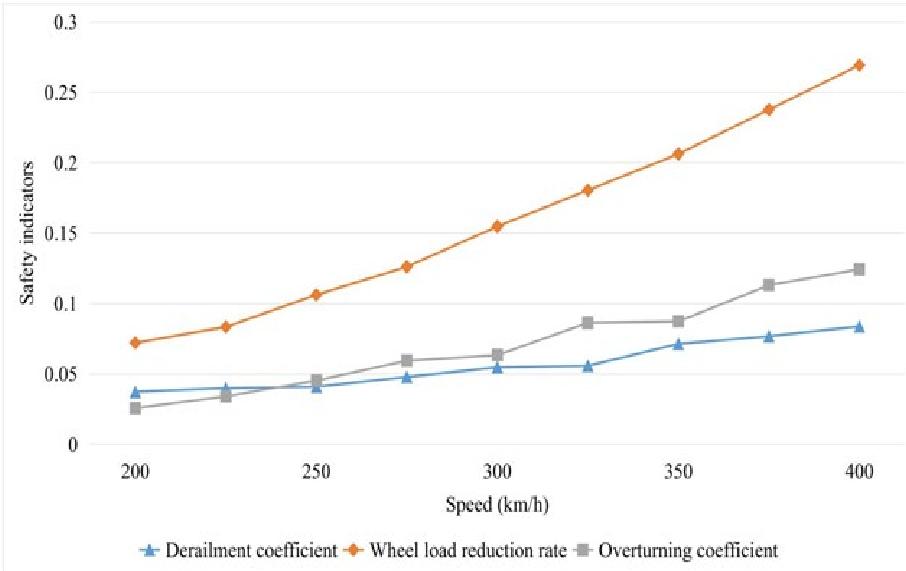

Figure 3. Variation trend of vehicle operational safety indicators with respect to the operating speed

Upon observation, it was discovered that when the vehicle moves along Curve 2, the deviation coefficient initially decreases as its speed increases and then increases again. At a speed of 190 km/h, the coefficient reaches its lowest point. The same trend is observed for the overturning coefficient and tier load variation; they both reach their lowest points at 170 km/h. Comprehensive simulation found that regardless of the simulated speed, the vehicle's safety remains below the expected limit. Further research identified practical issues, including energy consumption rate and cargo loading and unloading efficiency. From this research, a set of effective optimization strategies was derived. By evaluating various optimization factors such as train capacity, logistics transportation efficiency, transportation structure, transportation cycle, transportation volume, and logistics quantity in actual railway transportation, we can first apply the identified optimization factors and then verify their effectiveness. We will collect data from actual applications and compare and analyze it with the data before optimization. We will assess the effectiveness and results of our optimization plan and make adjustments and improvements as needed. Through carefully designed experiments combined with data collection and analysis, we can better assess the coordinated optimization of railway carrying capacity, thereby effectively controlling energy consumption and providing a scientific reference for decision-makers in the field of railway transportation.

5. Conclusions

Through systematic research, this analysis explores the factors for coordinated optimization of railway carrying capacity, with train speed being considered the most critical factor. Therefore, this study conducted an in-depth analysis of train speed to effectively identify and optimize factors such as energy consumption and carrying capacity. Through testing, it was found that adjusting the train's speed can effectively reduce fuel consumption while enhancing its load-carrying capacity. However, if the train speed exceeds expectations, it may significantly increase fuel consumption and pose more safety risks. Research has shown that an appropriate load level helps improve the train's transportation efficiency while reducing fuel consumption. However, if the load level is too high, it may cause the train to be overloaded, leading to a significant increase in fuel consumption. Therefore, cost savings and safety must be balanced. Through systematic research, it was found that appropriate train configuration not only helps reduce energy consumption but also enhances the freight's load-carrying capacity. Additionally, correct configuration helps reduce the cost of empty transportation. In the coordinated configuration of railway transportation, the train's speed, load, composition, etc., all need to be effectively controlled to reduce energy consumption, enhance the freight's carrying capacity, and ultimately achieve optimal results. When we attempt to improve a technology or service, we must simultaneously consider multiple aspects, such as safety, cost, and operability. Therefore, our decision-makers must consider various conditions to devise the best improvement plan. Through research on relevant issues, we can better guide our work, improve our work efficiency, and reduce our burden.

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