



Research on Optimization Methods for Cargo Loading and Distribution in Freight Train Set

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Abstract. In the modern logistics environment, effective cargo packing and stowage strategies are crucial to improving transportation efficiency and meeting customer needs. Improving cargo loading efficiency will help increase transportation capacity and reduce transportation costs. Freight EMUs are limited by the current small number of trains running, and domestic research on loading optimization of freight EMUs is insufficient. Therefore, in-depth research on cargo packing and stowage optimization methods in freight train units to improve transportation efficiency, reduce costs, and meet the needs of cargo transportation to the greatest extent has become an important plan for popularizing freight train units. This article first discusses the transportation characteristics of freight train units, reviews the current research status of cargo packing and stowage optimization at home and abroad, and summarizes various methods and algorithms used in existing research. Based on the analysis of the advantages and disadvantages of these methods, a useful reference is provided for this study. In view of the particularity of freight train unit transportation, through the idea of staged optimization, we discuss the constraints and optimization objectives for cargo loading containers and box car loading respectively, establish mathematical models for each, and use genetic algorithms, simulated annealing algorithms, and search trees etc., realized the optimization of cargo packing and container stowage in the EMU. Finally, through actual case analysis, the effectiveness and feasibility of the proposed method were verified, and improvement plans and prospects were proposed accordingly.

Keywords: Freight train sets, Packing problem, Loading optimization.

1 Introduction

In recent years, Chinese high-speed rail (HSR) has developed rapidly, with more than 6,000 high-speed trains currently in operation daily, making it a regular mode of transportation for the public. The swift development of HSR is evident in recent adjustments to railway planning. A network centered around major cities has been largely completed, covering cities, towns, and rural areas. This system ensures the radiating effect centered on hub cities, realizing interconnectivity between urban and rural areas, and providing convenient transportation between major provincial capitals. As the

advantages of HSR transportation—such as high punctuality, large capacity, and fast speeds—are increasingly recognized, more and more domestic scholars have conducted in-depth research on HSR express services and freight trains.

Zhou Shiping believes that using high-speed rail (HSR) for express delivery transportation is an inevitable choice for the future, as it will adapt to market changes while improving service quality and transportation capacity for the express delivery sector [1]. Wang Li and her team analyzed the factors hindering HSR express delivery in China and expressed optimism about the future development of HSR express services. They also provided suggestions on how to integrate HSR with the express delivery industry for mutual development [2]. Gao Lijie and others, through research on the future economic potential of HSR freight and existing operational plans, discussed the feasibility and challenges of running HSR freight services. They analyzed the main types of goods currently transported by HSR freight both domestically and internationally, and ultimately assessed the feasibility of launching HSR freight trains [3]. Qi Zhen conducted a feasibility study on the HSR express delivery business from technical and organizational perspectives, focusing on the policy support provided by the railway sector [4].

2 Analysis of Freight High-Speed Train Loading Problem

2.1 Overview

Freight high-speed train loading is a critical component of the entire high-speed rail freight operation. In this process, it is essential to meet the three-dimensional constraints of different cargoes and containers within the train, ensuring that the loading process adheres to safety and stability conditions, such as avoiding overloading, excessive weight, and imbalanced loading. Additionally, it is necessary to ensure that the center of gravity of the train car body remains within the permissible range during transportation, which is crucial for the rationality and efficiency of the loading scheme.

The optimization of freight train loading primarily refers to designing a loading solution after cargo has been packed, ensuring that the arrangement of containers satisfies all constraints, particularly safety-related conditions, while maximizing the utilization of loading space. In an ideal scenario, all containers would be safely loaded into the train carriages, but due to the varying sizes and weights of the containers and their large number, there may be situations where it is not possible to load them all safely. Therefore, this paper aims to find a loading scheme that is both safe and efficient under these constraints.[5]

The specific parameters of the CRH380B are shown in the following tables (Table 1 and Table 2), and the data will be used as reference for the model.[6]

Table 1. Vehicle Dimensions

Vehicle Length	Maximum Vehicle Width	Vehicle Distance	Roof to Floor Height
24590mm	3300mm	17500mm	3000mm

Table 2. Vehicle Weight Parameters

Empty Weight (AWO)	Capacity (85 passen- gers, 80 kg/person)	Auxiliary Equip- ment Weight	Body and Bogie Weight
34.52T	6.8T	0.6T	19.1T

Due to the large weight and volume of freight, the optimization of cargo space is more challenging than passenger space optimization, with a larger margin for optimization but greater difficulty. Current freight high-speed trains are mostly converted from passenger models, where the passenger capacity is typically taken as the upper limit for the freight loading capacity.

3 Models and Methods

3.1 Overview

This paper constructs a model for less-than-truckload goods, taking three-dimensional size constraints and weight constraints as constraints, and taking container volume and weight utilization rate as the objective function. The following assumptions are made for the model:

- (1) The container is rectangular,
- (2) An area within a container that does not restrict the position of goods
- (3) The goods are rectangular and the mass is evenly distributed
- (4) The shape and size of the goods remain unchanged, the goods have a certain stiffness and will not deform, there are no special goods that are not suitable for loading into containers, and there is no need to consider the possibility that the goods cannot be packed together.

- (5) The packing process does not consider the loading and unloading of goods

Based on the above assumptions, the following mathematical model is established:

The objective function of this problem is to optimize the utilization rate of container space (or weight utilization rate):

$$Z = \max \frac{\sum_{i=1}^n v_i}{V} \quad (1)$$

Z is the container volume utilization rate. v_i is the volume of the i -th cargo item. $i = 1, 2, \dots, n$.

Cargo weight constraint, m_i is the weight of the i -th cargo item, and M is the maximum weight capacity of the container.

$$\sum_{i=1}^n m_i \leq M \quad (2)$$

Cargo volume constraint:

$$\sum_{i=1}^n v_i \leq V \tag{3}$$

Three-dimensional size constraints for cargo loading:

$$\begin{cases} 0 \leq x_i + l_i \leq L \\ 0 \leq y_i + w_i \leq W \\ 0 \leq z_i + h_i \leq H \end{cases} \tag{4}$$

x_i, y_i, z_i are the corresponding coordinates of the i -th cargo item, l_i, w_i, h_i are the length, width, and height of the i -th cargo item. L, W, H are the length, width, and height of the container.

3.2 Spatial Partitioning

For the three-dimensional bin packing problem, heuristic algorithms can be considered to generate effective loading schemes. The loading plan can be formulated based on the following rules:

(1) Sequencing Rule

Generally, common sequencing methods are based on decreasing order of volume, weight, or the longest edge. If sequencing by weight, the cargo items are compared based on their weights, and the heaviest cargo is loaded first. The second heaviest is then loaded next, and so on, until all cargo is loaded. If some cargo items have similar weights, the longest edge of each item is compared, and the loading follows a descending order of the edge length.

(2) Positioning Rule

The positioning rule further defines the placement of cargo after the sequence is determined. A common positioning rule is to prioritize placing cargo in a corner of the container, and then filling in toward the center of gravity, continuing until the entire container is filled. This positioning rule is referred to as the corner placement rule.

For the remaining space generated by loading according to the above rules, space partitioning can be used to divide the remaining area of the container. Cargo is then continuously added to the divided spaces, generating new subspaces. Figures 1 illustrates the partitioned layout of the container.[7]

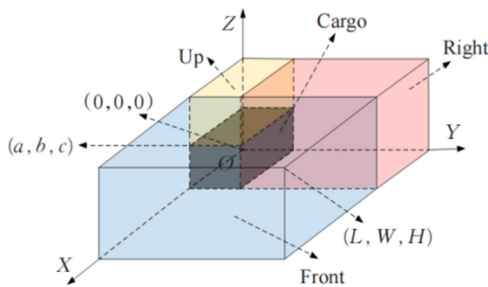


Fig. 1. Container Partitioning Layout

4 Experimental Results

The three-dimensional bin packing algorithm studied in this paper is implemented using the MATLAB programming language. Test cases are used to evaluate the performance of the algorithm, yielding specific loading results, a visualized packing model, and performance metrics of the loading process.

The objective of the test is to allocate a set of cargo items, each with different dimensions, quantities, and weights, into several containers with fixed three-dimensional dimensions and maximum weight capacity, while maximizing the container's volume utilization under the given constraints. Additionally, the fitness value of the obtained solution needs to be evaluated and analyzed.

After testing the data, the weight utilization rate and space utilization rate are displayed using line graphs, as shown in the figure below. Seeing Fig.2(a)(b).Through continuous iterations, the performance of the algorithm improves gradually. The weight utilization rate reaches 99%, and the volume utilization rate is 100%, indicating that all cargo has been loaded.As shown in Figure.3.It can be used as a visual reference for loading.

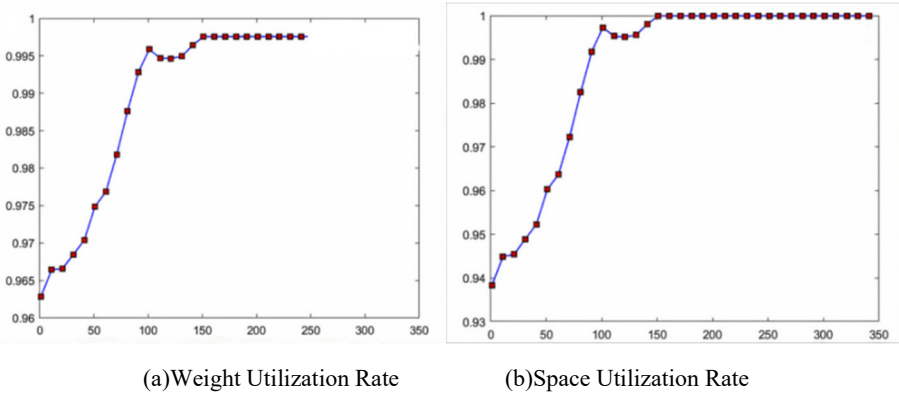


Fig. 2. Changes in Weight Utilization Rate and Space Utilization Rate.

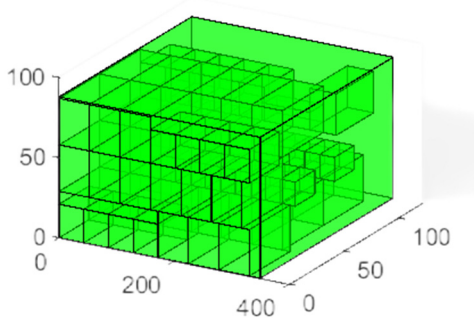


Fig. 3. 3D Diagram of Container Loading Status.

After testing, the loading scheme and related performance parameters were obtained, achieving a relatively ideal result, which proves that the model performs well and the optimization meets expectations. The model reduces the waste of empty space. It shows a significant improvement compared to the standard algorithm.

5 Conclusions and Outlook

In this paper, a preliminary model for the cargo loading of freight trains was constructed by making assumptions about the three-dimensional dimensions, volume, and weight of containers and goods, which align with the transportation needs of freight trains. The positioning and sequencing problems were addressed, and a space partitioning scheme was completed. The hybrid algorithm was then studied, ultimately leading to the development of a comprehensive three-dimensional loading optimization algorithm. This resulted in an optimal loading plan, achieving the optimization of cargo loading for freight trains.

The bin packing optimization in this paper still has areas that need improvement and further research due to the complexity of the problem and limited capabilities. For practical issues such as convenience, further algorithmic design and research are needed.

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