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Research Article

Optimization for Stop Plan of Passenger-Like Container Train with Container Distributions and Train Utilization Rates

Yang Xia,[1] **Yuguang Wei**,[1] **Yihuan Lai**,[2,3] **and Qi Zhang**[1]

[1]*Department of Transportation Management Engineering, School of Traffic and Transportation, Beijing Jiaotong University, Beijing 100044, China*
[2]*Shenzhen Urban Transport Planning Center, Shenzhen 518034, Guangdong, China*
[3]*Shenzhen Key Laboratory of Information and Traffic Engineering, Shenzhen 518034, Guangdong, China*

Correspondence should be addressed to Qi Zhang; qizhang@bjtu.edu.cn

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The railway container transportation is attracting more and more attention in China. In order to improve the service quality, a novel concept of passenger-like container train is proposed, which can reduce the accumulation time of containers at the origin station and increase the train frequency compared with the traditional container through train. With the aim of generating optimal operation strategies for passenger-like container trains, this paper establishes an optimization model for the train stop plan problem, in which the objective is to minimize the total number of stops. In addition, the specific container-to-train distribution and the utilization rate of each individual train are considered. The proposed model is a mixed-integer linear programming one, which can be solved by using the CPLEX solver. Finally, the numerical experiments are performed to test the effectiveness of our model by using a simple railway line and the China Railway Express corridor as examples. The results prove the advantages of our method.

1. Introduction

In recent years, with the adjustment of China's economic structure, great changes have taken place in the freight transport market. The transportation demand for high-value merchandise is increasing sharply, and the timeliness of freight transportation is highly required by the shippers. In this context, container transportation will play an important role in the freight transportation. As a major form of container transportation, railway container transportation is advocated by the country for its advantages of large transport capacity, low cost, and environmental friendliness. But in fact, the market share of the railway container transportation in China is very small, which is far lower than that of the road container transportation. Therefore, in order to enhance market competitiveness, it is critical for railway operators to provide high-quality services to shippers and to improve the utilization efficiency of the limited available railway infrastructure.

At present, the China Railway Corporation actively promotes container direct transportation to improve the speed of container service. A container through train can reduce the train running time significantly because it does not enter the marshalling yard and disintegrate during its operation process. However, it relies on the stable and sufficient container flow between the origin and terminal stations. Once the container flow is insufficient, the total transportation time would increase because the time consumption caused by the container accumulation process at the origin station is too long, thus failing to meet the shipper's expectations and resulting in the loss of containers.

Based on the characteristic of easy handling of containers, the novel concept of passenger-like container train (PLCT) is proposed to solve this problem. The organization process of passenger-like container train is described in Figure 1. The containers accepted for carriage need to be sent to the platforms to wait for a train just like passengers. The passenger-like container train adopts the mode of loading

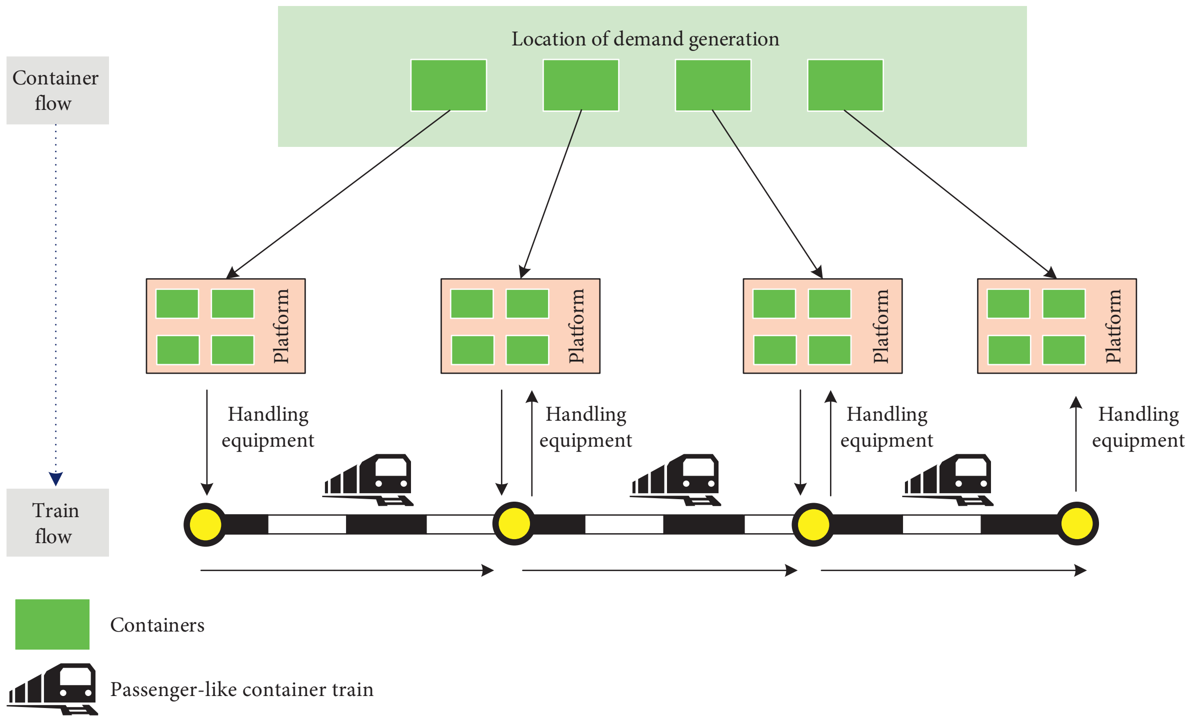

Figure 1: The organization process of a passenger-like container train.

and unloading containers on the arrival-departure track. When a passenger-like container train stops at the arrival-departure track beside the platform, the containers are loaded/unloaded from/to the platform by the handling equipment (e.g., reach stacker and gantry crane). Upon the completion of loading and unloading operations, the train leaves directly. This process is repeated at the intermediate stations until the train arrives at the terminal station.

It should be noted that the layout of existing yards in China does not support the operation of passenger-like container trains. Therefore, the new arrival-departure tracks and the corresponding platforms should be constructed. Furthermore, the trains are in fixed formation, which is similar to passenger trains.

Compared with the traditional container through train, the passenger-like container train has the following advantages:

(1) A passenger-like container train can stop at the intermediate stations to transport the containers from there. These containers can be used as the supplementary container flow to reduce the accumulation time at the origin station, with high utilization rate of train capacity at the same time.

(2) It can enhance the transportation accessibility and expand the radiation scope of railway container transportation, attracting more container flow to railway transport. As a result, the train frequency will increase and the service quality can be improved.

(3) The dwell time at the intermediate stations would not be long if the stations are equipped with adequate handling equipment to ensure the efficiency of loading and unloading operation. This is because that the transportation organization of the passenger-like container train is free from the marshalling yard and the train does not disintegrate and reconnect. Consequently, the transit speed will not be greatly affected.

In conclusion, the passenger-like container train can improve the timeliness of railway container transportation and increase the traffic volume, which are of great significance for railway operators to enhance the market competitiveness of railway container transportation.

By introducing the concept of passenger-like container train, the passenger-like container train stop planning problem (PLCTSPP) arises then, which determines the set of stations at which each train will stop. The PLCTSPP is critical for the railway operators to transport containers from their origins to their destinations at the minimum cost. A reasonable train stop planning model is a basic tool for providing efficient transport services.

In this paper, we propose an optimization model for the PLCTSPP together with container distributions. Unlike a passenger, who can decide which train to take by purchasing a ticket, the detailed assignment of containers to trains must be determined by the railway operators and certain operations in a station are affected by the result of container distributions (e.g., placing the corresponding containers on the platform in advance). Hence, it is meaningful to consider the container distributions to different trains during the process of optimizing stop plan because it explicitly provides a reference for the railway operators to work out the distributions in real-world operations. In addition, the railway company in China puts a high value on the resource utilization efficiency. Take the traditional container through train for example; only when the accumulated containers at the origin station reach full axis, can a train be dispatched. In this sense, we address considerations of the utilization rate of each involved passenger-like container train in our model. The objective of the proposed model is to minimize the total number of stops for all the trains.

The main contributions of this paper are listed as follows:

(1) The new concept of passenger-like container train is proposed in this paper in order to improve the service quality of the railway container transportation.

(2) A mixed-integer programming model is established to optimize PLCTSPP. In the model, the constraint of utilization rate of every single train is newly proposed, which has not been studied in the literature.

(3) We implement the numerical experiments on a sample railway line and the China Railway Express corridor to demonstrate the performance of our model.

The remainder of this paper is organized as follows: Section 2 contains a brief review of the related train stop planning literature. In Section 3, the proposed stop planning model for passenger-like container trains is introduced. Section 4 is devoted to the description and evaluation of the numerical experiments. The final section presents the major conclusions and gives an outline of the future research tasks.

2. Literature Review

The train stop plan is one of the crucial planning problems that the railway operators must face. An efficient stop plan can not only decrease the total travel time of the transportation object but also reduce the operation cost. Therefore, it has drawn a great deal of attraction from the researchers. It should be noted that all studies mentioned in this paper are about passenger trains because of the distinctions of the organization mode between passenger trains and freight trains. Although our research objective is container trains, the related literature can provide us with a basic method to optimize the PLCTSPP, with the reason that the reformed organization mode resembles that of the passenger trains.

In the literature, most researchers consider the train stop plan as a key element of the line plan, and these approaches can generally be classified into two categories: (1) The stop strategy is prespecified. The line plan is optimized under the premise that the all-stop pattern is adopted in [1–3]. This stop strategy is widely used in the urban rail transit, such as Hong Kong metro in [4]; however, it will increase the travel time of passengers. Hence, many scholars emphasize other stop strategies, like zonal pattern and express pattern (i.e., no-stop pattern). The line plan problem for a multitype railway system is studied in [5–7]. In the system, the stations are categorized as Regional (R) for type 1, Interregional (IR) for type 2, and Intercity (IC) for type 3. Accordingly, the trains operated in the system have the similar categorization. The R train will stop at all stations along its route, the IR train will skip the stations of type R and stop at stations of type IR and IC, while the IC train will stop only at stations of type IC. The normalized stop patterns can decrease the travel time and facilitate the arrangement of cycle timetables. In [8], the authors optimize the train stop patterns (i.e., all-stop, short-turn and express pattern) and the train frequency based on the consideration of heterogeneous demand. The constraints of frequency conservation, capacity, and fleet size are proposed to formulate the rigorous mathematical model. (2) The stop strategy is not prespecified. In [9], focused on the Chinese high-speed railway network, a phased line plan approach is described, in which the stations and trains are defined according to two classes, namely, Higher-classified and Lower-classified stations/trains. Firstly, the Higher-classified trains are generated from the line pool, which includes the associated trains with all possible stop patterns for each line. Secondly, the schedule of Lower-classified train stops is achieved. In [10], the possible train OD and the corresponding train route with different stop patterns are added into a line pool firstly. Then, a mixed-integer programming based on the theory of multicommodity flow is developed to choose the best trains from the pool. The Lagrange relaxation heuristic algorithm is designed to solve the model. Two integer programming models are formulated for the line plan problem on the condition of whether the stop patterns are given or not in [11]. And a column generation approach is designed to solve the model which assumes the stop patterns are not provided in advance.

Meanwhile, some researchers pay their attention to the train stop plan problem for railway corridors, which are also our research environment. The literature [12, 13] both concentrate on the optimal train stop plan for Taiwan high-speed railway corridor. One difference between them is that the fleet size is treated as the decision variable in the latter. A nonlinear programming model is built to optimize the stop plan for high-speed railway line in [14], which stresses the concept of the node service. The above studies all assume that the passenger demands are known and fixed. However, in real world, the passenger flow will change every day. On this basis, a change-constrained programming model is formulated using uncertain variables that present the uncertainty of passenger demands in [15]. In addition, some researchers integrate the trains stop plan with other planning problems to optimize collaboratively, such as [16, 17]. Both studies analyze the relationship between the stop plan and the train timetable and proposed integrated optimization model.

As analyzed in Section 1, it is essential to track the utilization rates of each passenger-like container train in the PLCTSPP; and the specific container-to-train assignment will greatly affect the utilization rates. In the literature of the passenger train stop plan problem, though few researches involve the passenger-to-train assignment into the model, useful information is provided for us to embed the container distributions into the model. In [18], the authors establish a bi-level model, in which the general travel cost and the number of stops are optimized in the upper level model and the passenger flow assignment can be generated in the lower level model based on the multiclass user equilibrium. The study [19] combines the restricted passenger flow assignment into the train stop plan problem. The proposed assignment procedure can route passenger travel paths freely in a train network. Based on [19], Qi et al. [20] consider the detailed passenger distributions and formulated an integrated model to optimize the train stop plan and operation zone.

3. The Proposed Mathematical Model

3.1. Problem Statement. As mentioned above, it is necessary to optimize the PLCTSPP considering the container distributions. On the one hand, it is the railway operators' duty to assign the containers accepted for carriage to different trains. As the number of origin and destination (OD) pairs and trains increases, this manual work would become very difficult. And integrating the container distributions into PLCTSPP can exactly provide useful information for the operators to reduce the work complexity. On the other hand, the specified container distributions exert a great influence on the utilization rate of trains. An unreasonable distribution may lead to the imbalance of utilization rate between different trains.

For convenience, we present an example to illustrate the importance of incorporating the container distributions into the PLCTSPP. Consider a railway line with four stations and three links. The OD demands on this line are shown in Figure 2. The maximum loading capacity of a train is assumed to be 10. According to the edge load, it can be deduced that two trains are need to be operated from station A to D to transport all the demands.

Two possible different stop plans, which are indexed by (a) and (b), respectively, are illustrated in Figure 3. A solid dot indicates that the train stops at the station, while a hollow dot means that the train does not stop at the station. Hence, train 1 is a through train, whereas train 3 is scheduled to stop at station B. For train 2 and train 4, they must stop at all stations to satisfy container demands. Furthermore, the detailed container distributions (i.e., q^1_{AB}, q^1_{AC}, q^1_{AD}, q^1_{BC}, q^1_{BD}, and q^1_{CD} on train 1; q^2_{AB}, q^2_{AC}, q^2_{AD}, q^2_{BC}, q^2_{BD}, and q^2_{CD} on train 2; q^3_{AB}, q^3_{AC}, q^3_{AD}, q^3_{BC}, q^3_{BD}, and q^3_{CD} on train 3; and q^4_{AB}, q^4_{AC}, q^4_{AD}, q^4_{BC}, q^4_{BD}, and q^4_{CD} on train 4), which are represented by different coloured rectangles, are also illustrated in Figure 3. The values in the rectangles are the number of containers that each train carries. Obviously, since train 1 does not stop at stations B and C and train 3 does not stop at station C, the value of q^1_{AB}, q^1_{AC}, q^1_{BC}, q^1_{BD}, q^1_{CD}, q^3_{AC}, q^3_{BC}, and q^3_{CD} must be set to 0, with the purpose of avoiding conflict.

As shown in Figure 3, there are some unemployed "seats" on each train, leading to waste of loading capacity. Here, we use the arithmetic mean of the sum of the occupancy rates of each section to express the utilization rate of a train. Take train 2 as an example, the total numbers of containers on train 2 in sections (A, B), (B, C), and (C, D) are q^2_{AB}, $q^2_{\mathrm{AC}} + q^2_{\mathrm{BC}} + q^2_{\mathrm{BD}}$, and $q^2_{\mathrm{BD}} + q^2_{\mathrm{CD}}$, which are equal to 4, 7, and 7, respectively. Accordingly, the occupancy rates of each section are 0.4, 0.7, and 0.7, respectively. Next, the utilization rate of train 2 can be calculated, which is 0.6 (i.e., $(0.4 + 0.7 + 0.7)/3$). Similarly, the utilization rates of trains 1, 3, and 4 are 0.4, 0.5, and 0.5, respectively. If the minimum utilization rate of a single train is set to 0.5 by the railway operators, the stop plan (a) would be infeasible because the utilization rate of train 2 does not satisfy the requirement. In other words, only stop plan (b) can be implemented in real-world production, even though one more stop should be made.

3.2. Assumptions and Notations

3.2.1. Assumptions. The above analysis reflects the relationship between stop plan, container distributions, and utilization rates of each train. In this paper, our aim is to formulate an optimization model to optimize the stop plan and container distributions collaboratively, guaranteeing the utilization rate of each train at the same time.

For modeling convenience, the following assumptions are used for the formulation of a rigorous mathematical model:

(1) Only one direction is considered on a railway line, the stop plan in the opposite direction of the line can be handled analogously
(2) The OD demands along a railway line are known in advance and treated as fixed value
(3) The containers are transported from the origin to the destination only by one train, which means no transfer happens
(4) The station capacity is assumed to be large enough to receive and dispatch all the trains
(5) The loading capacity of all the involved trains is the same

3.2.2. Notations. The related symbols, parameters, and decision variables are listed in Tables 1 and 2, respectively.

3.3. Mathematical Formulations. Given a railway line and the corresponding OD demands, the number of trains needed to transport the containers can be calculated according to the edge load of each section. Based on the information, the set of stations at which each train will stop should be determined, and the container distribution plan should be obtained simultaneously, which ensures that the utilization rate of each individual train meets the requirements.

In this subsection, the objective function and constraints are formulated to obtain the desired solution.

3.3.1. Objective Function. This paper focuses on the total number of stops of all trains. The objective function is given as follows:

$$\min z = \sum_{k\in T}\sum_{i\in S} x_{ki}. \tag{1}$$

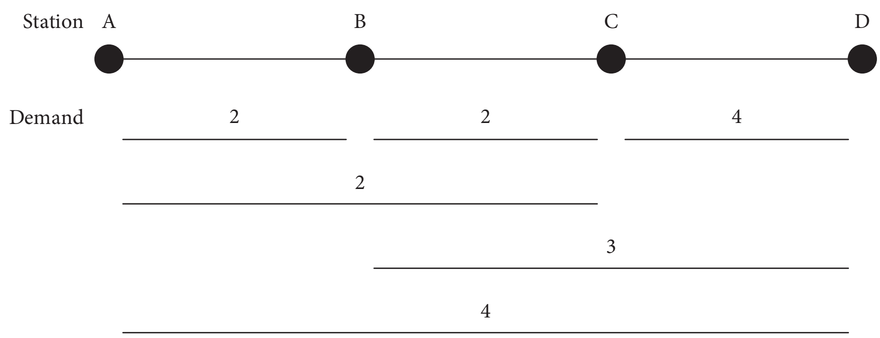

Figure 2: An illustration of a railway line and corresponding traffic demand.

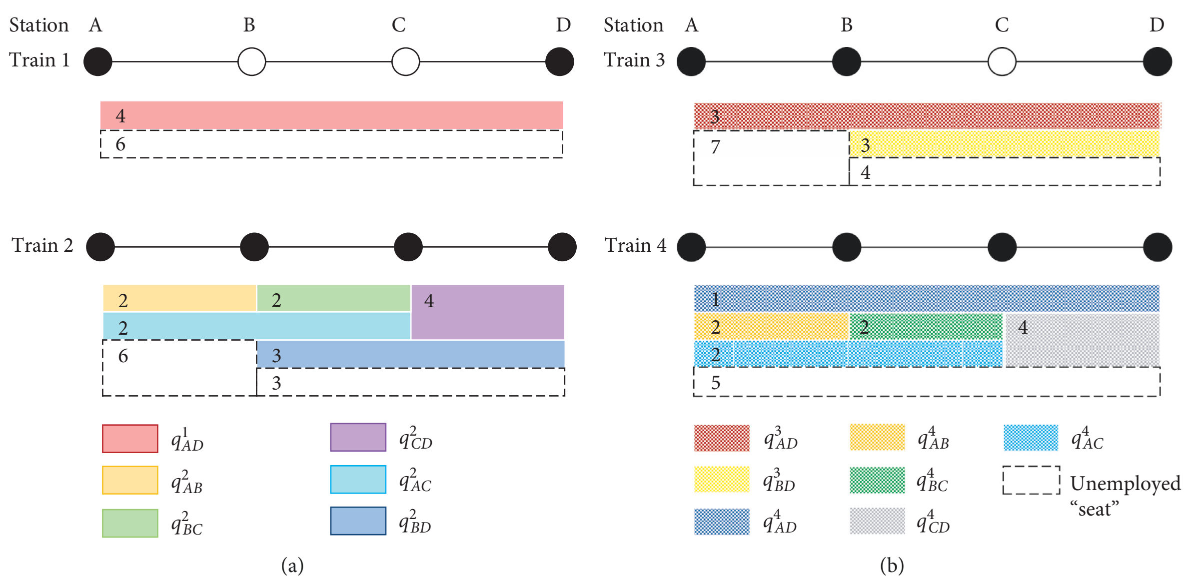

Figure 3: An illustration of container distribution between trains with different stop plans.

Table 1: Symbols and parameters used in the formulation.

Symbol	Definition
S	Set of stations on the considered railway line
$\mathbf{T}$	Set of trains that need to transport all the demands
$\lvert S\rvert$	Number of stations; then, $\lvert S\rvert - 1$ represents the number of sections
$\lvert T\rvert$	Number of trains
i, j, h	Index of stations, $i, j, h \in S$, can also be index of sections
k	Index of trains, $k \in \mathbf{T}$
Q_{ij}	Number of containers to be transported from station i to j
C	Train loading capacity
α	Minimum utilization rate stipulated by railway operators
M	A sufficiently large number

Table 2: Decision variables used in the formulation.

Variable	Definition
x_{ki}	0-1 binary variable: 1 if train k stops at station i; 0 otherwise
q^k_{ij}	Distributed number of containers traveling from station i to j on train k

Table 3: The container demands along the considered railway line.

Origin/destination	A	B	C	D	E
A	—	10	30	10	80
B	—	—	40	50	20
C	—	—	—	20	30
D	—	—	—	—	10
E	—	—	—	—	—

The railway companies are concerned with the interests of shipper and themselves in the meantime. They expect to transport the containers at the minimum cost and time. And the number of stops exactly reflects the interests of both sides. On the one hand, the dwell time of passenger-like container trains brought by a stop is much larger than that of passenger trains due to the loading and unloading operation. Thus, reducing the number of stops contributes apparently to the timeliness of railway container transportation. On the other hand, an increased number of stops will influence the carrying capacity of a railway line negatively and expand the turnaround time of rolling stocks, which will cause higher operation costs. From these perspectives, it is appropriate to use the total number of stops as the evaluating index to formulate the objective function.

3.3.2. Container Demand Constraints. All the containers should be transported from their origins to their destinations. Therefore, the container demand constraints are formulated as shown in the following equation:

$$\sum_{k\in T} q_{ij}^{k} = Q_{ij}, \quad \forall i, j \in S, \ i < j. \tag{2}$$

The left-hand side indicates that the containers of same OD can be assigned to different trains, which is the decision content of the container distribution plan.

3.3.3. Train Stop Constraints. The train stop plan should be consistent with the distribution plan. The following set of constraints reflects this concern:

$$q_{ij}^{k} \le M \cdot x_{ki}, \quad \forall k \in T, \ \forall i, j \in S, \ i < j, \tag{3}$$

$$q_{ij}^{k} \le M \cdot x_{kj}, \quad \forall k \in T, \ \forall i, j \in S, \ i < j, \tag{4}$$

$$x_{ki} = 1, \qquad \forall k \in T, \ i = 1, \ i = |S|. \tag{5}$$

Equations (3) and (4) state the relationship between decision variables q_{ij}^k and x_{ki}. If the containers from station i to station j are transported on train k (i.e., $q_{ij}^k > 0$), then train k must stop at station i and station j (i.e., $x_{ki} = x_{kj} = 1$) to enable the containers to be loaded at station i and unloaded at station j. Conversely, if train k does not stop at station i or j, the decision variable q_{ij}^k must take the value of zero to satisfy these constraints. Specially, if no containers from stations i and j are assigned to train k (i.e., $q_{ij}^k = 0$), in order to minimize the objective function, the decision variables x_{ki} and x_{kj} will take the value of zero, though both zero and one can be their values. Moreover, as for the value of M, it can be equal to C because the maximum value of q_{ij}^k cannot be larger than the train loading capacity. Equation (5) shows that a train must stop at the origin and terminal stations.

3.3.4. Loading Capacity Constraints. The number of containers that a train transports must be less than the train loading capacity, leading to the following constraints:

$$\sum_{i\le h}\sum_{j>h} q_{ij}^{k} \le C, \quad \forall k \in T, \ \forall h \in \frac{S}{\{|S|\}}. \tag{6}$$

When train k stops at a station, some containers will be unloaded from the train, while some containers will be loaded to the train, which results in the changes of the number of containers on train k between different sections. Hence, whether the conditions are met or not is checked by sections.

3.3.5. Utilization Rate Constraints. This constraint is a new one put forward in this paper, compared with other models for train stop planning problem. The constraints are as follows:

$$\sum_{h=1}^{|S|-1}\sum_{i\le h}\sum_{j>h} \frac{q_{ij}^{k}}{(|S|-1)} \cdot C \ge \alpha, \quad \forall k \in T. \tag{7}$$

The utilization rate constraints embody the difference between railway container transportation and railway passenger transportation. In passenger transportation, the utilization rate is one of the common indexes adopted to evaluate the stop plan or line plan of passenger trains. However, it focuses on the total utilization rate of all trains typically. In this paper, we track the utilization rate of every single train. Only when the utilization rate of a train exceeds the minimum value set by railway operators, can the train be dispatched to transport the containers. As mentioned above, the arithmetic mean of the sum of the occupancy rates of each section is used to express the utilization rate of a train.

4. Numerical Experiments

This section provides two numerical experiments of the proposed passenger-like container train stop planning model in order to demonstrate the practicability of our model. An illustrative example is performed primarily, where the relationship between stop plans, distribution plans, and train utilization rates are analyzed. We also design a large-scale example using the China Railway Express corridor to conduct sensitivity analysis. Considering that the decision variables q_{ij}^k are integer, the decision variables x_{kj} are binary, and the objective function and the constraints are linear, the model we establish is a mixed-integer programming (MIP) one, which is normally an NP-hard problem. In this paper, the Python language is adopted because of its mature package repository which is helpful to program the model, and the CPLEX solver is called to obtain the solutions. Due to the limited hardware resources, all experiments were tested on a PC (WIN 10, Intel Core i5-8265U, 1.80 GHz, and 8GB RAM).

4.1. A Small-Scale Case Study. Since the number of OD pairs increases sharply with the expansion of a railway line's scale, in order to show the detailed container distributions intuitively, a small-case study is tested first.

Here, a sample railway line with 5 stations and 4 sections is considered. The stations are named A, B, C, D and E, respectively. We only take the outbound direction into account, namely, from station A to station E. The corresponding OD demands are listed in Table 3, from which it can be calculated that the maximum number of containers on each section (i.e., edge load) is 230. The loading capacity of a train is set to 50 in this experiment. Then, it is obvious that 5 passenger-like container trains should be operated to transport all the containers. For the sake of making ends meet, the value of minimum utilization rate is assumed to be 50%.

It took 0.1 s to complete the computation process. The obtained objective value is 17, which means 17 total stops are made by all the trains. Additionally, the relative gap between output value and the best solution is zero, indicating that the generated solution is exactly the best solution. The corresponding stop plans and distribution plans are shown in Figure 4.

Clearly, the five trains get different stop plans and container distribution plans to transport all the containers at the minimum cost. Concretely, train 1 does not stop at station C because it only carries the containers of the OD pairs BD and DE. For section (A, B), there are no containers on train 1, while the train is fully loaded on sections (B, C) and (C, D). And it transports 10 containers from station D to station E. Train 2 does not stop at station B since no containers need to be loaded and unloaded there. Train 3 is a through train, stopping at no intermediate stations. There are no unemployed "seats" on each section. For the remaining two trains, train 4 does not stop at station D and train 5 does not stop at station C or D, in order to keep consistent with their container distributions. Furthermore, the utilization rates of all trains are marked in Figure 4 as well, which are 55%, 75%, 100%, 50%, and 75%, respectively.

It is interesting to find out how the distribution plans affect the utilization rates of the involved trains. With this aim, we removed constraint (7) from the proposed model and solved the part of model left. The corresponding solution is illustrated in Figure 5. Comparing two solutions, it can be found that the stop plans of the 5 trains remain the same. However, slight changes take place in the distribution plans and the utilization rates of train 4 and train 5 due to the ignoring of the utilization rate constraints. The utilization rate of train 4 drops to 45%. As a result, the obtained solution cannot be applied if the railway operators have requirements for the minimum utilization rate of each train.

At last, the experiments are carried out to explore how the solutions change with the increase of the value of parameter α. Here, we set α to 70%, and the returned solutions are shown in Figure 6. The following discrepancy can be concluded by comparing the solutions of initial experiment. Firstly, the specific container assignments among different trains are not identical any more. Secondly, the consequent utilization rate of each train changes into 70.5%, 70.5%, 74%, 70%, and 70%, respectively. Thirdly, the stop plans vary from those in the primary solutions. The total number of stops made by the five trains grows to 18. Whether the new solutions are adopted depends on the railway operators' preferences with respect to the significance of the total number of stops.

4.2. Large-Scale Experiment. The China Railway Express is highly valued by the Chinese government due to its vital role in transporting containers between China and Europe. As consequence, we consider the Lianyungang-Alataw pass corridor as our large-scale experiment corridor. At present, the express train operates from Lianyungang to Alataw pass directly, and the operation frequency is usually one train every two or three days because of the limited traffic volumes.

4.2.1. Data Preparation. In this paper, twelve stations on the corridor are chosen as intermediate stations where the passenger-like express train can stop at to increase the frequency and enhance the service quality. The corridor is shown in Figure 7.

Since the newly proposed organization mode has not been realized in real world, it is almost impossible to acquire the specific information on relative OD-based container demands. Hence, the detailed container demands in the experiments are all assumed values, as shown in Table 4. In Table 4, the symbols S1 to S14 represent all the stations on the corridor, in the order from Lianyungang to Alataw pass (i.e., S1: Lianyungang; S14: Alataw pass). Although these values may not be completely accurate, they by no means affect us to test the model. Once provided, the accurate demand data can be brought into the model to obtain the solution.

Here, influenced by the length of the arrival-departure track, a passenger-like express train is supposed to be consisted of 50 container flatcars. Since a flatcar can load two containers, the maximum loading capacity of a passenger-like express train is 100 containers.

Based on the above information, the maximum flow value of all the sections is equal to 349, implying that 4 passenger-like express trains should be operated, which indicates the superiority of our proposed organization mode of railway container transportation (i.e., the frequency of traditional container through train is only 0.3).

In addition, the minimum utilization rate of each train is assumed to be 60%.

4.2.2. Computational Results. After approximately 30 seconds of computation, the objective value 32 is obtained, accounting for about 57% of the total number of stops if all trains stop at every station. The stop plan for each single train is presented in Figure 8. The specific container distribution plans were also acquired. However, due to the space limitations, they are not displayed here.

Specifically, train 1, train 2, and train 3 stop at a portion of intermediate stations in order to reduce the total number of stops, while train 4 stops at all intermediate stations to ensure that all containers can be transported. Among the four trains, train 3 stops the least times, only at two stations (i.e., Xi'an and Urumchi). Moreover, it is obvious that the service frequency (i.e., the total number of stops made by all trains at one station) of each station is different on the score of OD-based demands. For example, from Table 4, 90/65 containers are loaded/uploaded at Zhengzhou station, resulting in 3 trains stopping at Zhengzhou station. By contrast, Wuwei station is the origin and destination for 28 and 26 containers, respectively; hence, only train 4 is scheduled to stop at this station to provide necessary service. Additionally, the utilization rates of the four trains are 66.5%, 66.3%, 60%, and 85%, respectively.

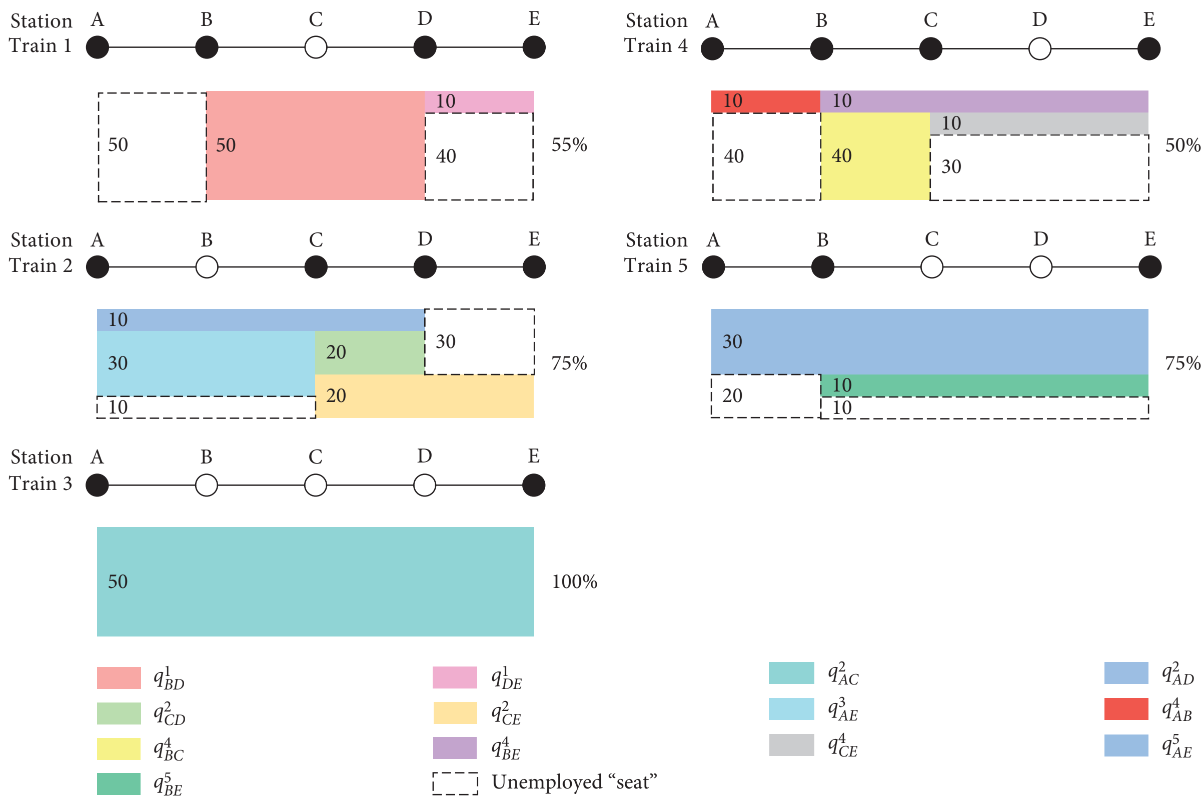

Figure 4: The specific stop plans and distribution plans for the sample railway line.

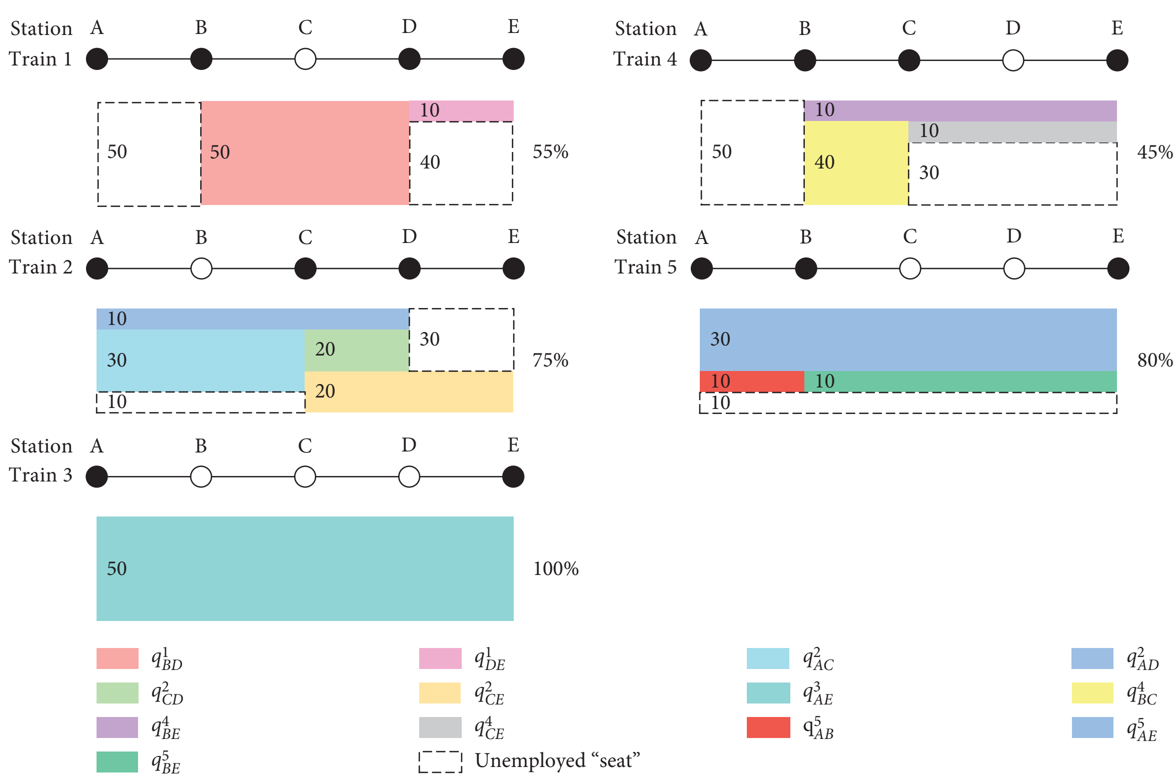

Figure 5: The obtained solutions when utilization rate constraints are removed from the model.

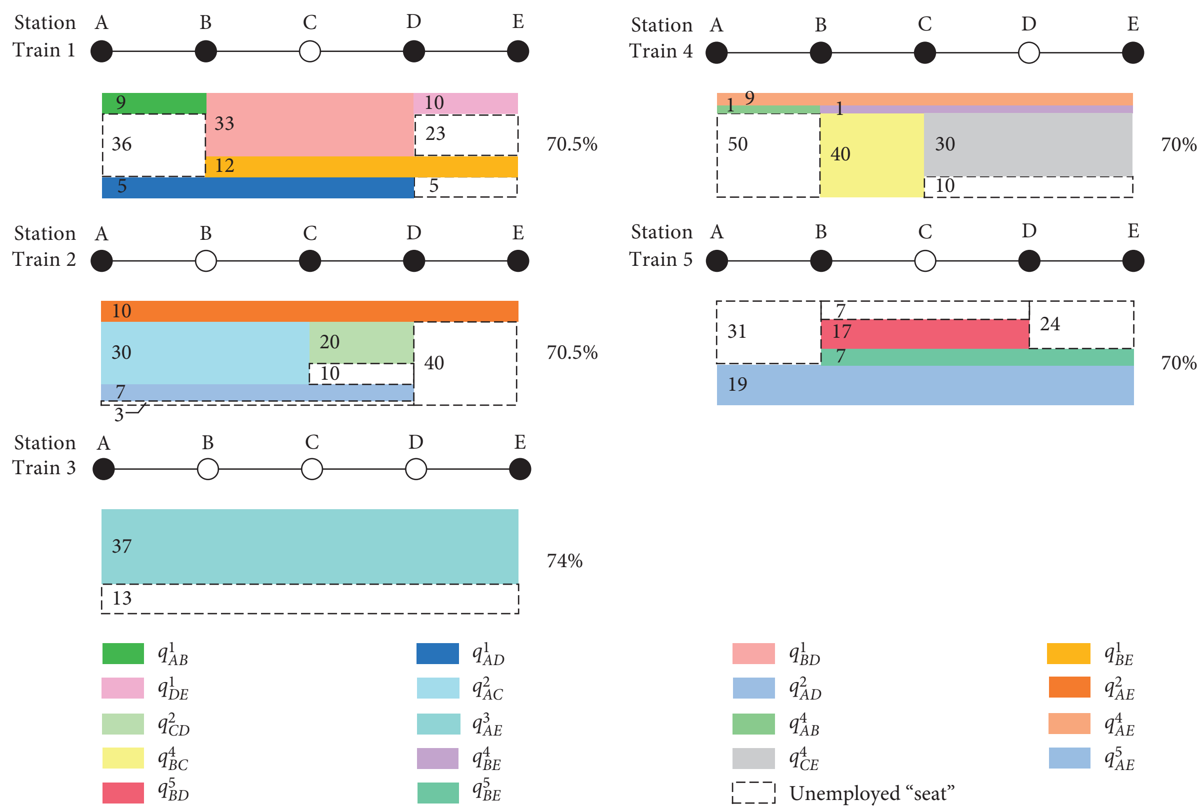

Figure 6: The obtained solutions when the value of minimum utilization rate is set to 70%.

Figure 7: Map of the Lianyungang-Alataw pass corridor.

4.2.3. Sensitivity Analysis. In this subsection, different values for the minimum utilization rate parameter α and train loading capacity C are set in two further performance experiments of our model:

(1) In order to conform to the reality of freight transportation in China, the minimum utilization rate for each involved train is introduced in this paper, which is determined by the railway operators. In general,

Table 4: The assumed container demands on the Lianyungang-Alataw pass corridor.

O/D	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
S1	—	22	8	10	24	18	18	18	14	0	2	3	12	30
S2	—	—	8	7	20	8	10	8	13	3	3	4	6	12
S3	—	—	—	6	11	5	8	5	3	1	2	1	4	4
S4	—	—	—	—	10	6	6	7	8	2	2	4	4	6
S5	—	—	—	—	—	9	18	8	18	4	3	6	8	16
S6	—	—	—	—	—	—	4	8	5	3	1	5	4	6
S7	—	—	—	—	—	—	—	12	16	4	5	9	11	14
S8	—	—	—	—	—	—	—	—	14	3	4	4	5	10
S9	—	—	—	—	—	—	—	—	—	6	8	4	10	14
S10	—	—	—	—	—	—	—	—	—	—	6	5	9	8
S11	—	—	—	—	—	—	—	—	—	—	—	6	8	10
S12	—	—	—	—	—	—	—	—	—	—	—	—	6	16
S13	—	—	—	—	—	—	—	—	—	—	—	—	—	20
S14	—	—	—	—	—	—	—	—	—	—	—	—	—	—

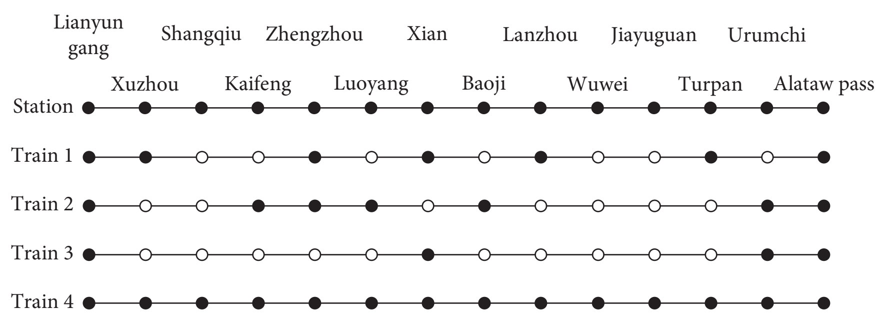

Figure 8: Stop plan for the Lianyungang-Alataw pass corridor.

Table 5: The obtained results with different values of the parameter α.

α value	Computation time	Total stops	Utilization rates
0	$59''283$	32	66.2%, 79.9%, 53.8%, 77.8%
10%	$1'30''074$	32	66.8%, 82.8%, 74.3%, 53.8%
20%	$1'18''121$	32	66.8%, 82.8%, 74.3%, 53.8%
30%	$14''834$	32	63.8%, 79.2%, 67.5%, 67.2%
40%	$22''144$	32	68.8%, 83.2%, 52.6%, 73.2%
50%	$39''027$	32	66.9%, 85.2%, 69.1%, 56.5%
60%	$22''904$	32	85.0%, 66.5%, 66.3%, 60.0%
65%	$1'17''561$	33	65.4%, 72.2%, 74.6%, 65.5%
69%	$42''909$	33	69.1%, 69.0%, 70.7%, 69.0%
70%	No solution exists		

Table 6: The obtained results with different values of the parameter C.

C value	Computation time	Train number	Flatcar number	Total stops	Maximum α (%)
60	$1:12'46''179$	6	180	43	77
70	$29'07''482$	5	175	38	79
80	$25'25''703$	5	200	37	69
90	$2'12''367$	4	180	34	77
100	$39''027$	4	200	32	69

different values of this parameter represent the emphasis on enhancing railway resource utilization. In this set of experiments, we test the influence of the parameter α on the generated stop plans and container distribution plans. Furthermore, since the total container demands do not exceed the train loading capacity, the parameter α cannot take an arbitrary value, disregarding the relationship between the specific demands and the train loading capacity. With this set of experiments, the maximum value of parameter α can be obtained as a reference for railway operators. The detailed results are shown in Table 5.

As shown in Table 5, it can be clearly found that the maximum value of parameter α that can be taken is 69% because no solution exists when it is set to 70%. In addition, one more stop should be made when we increase the value of parameter α from 60% to 65% because stricter requirement on the utilization rates will affect the detailed container-to-train distributions, which leads to the change of stop plans. It is also worth mentioning that the utilization rates of each train are all above 50% when the parameter α takes the value in the range of 0 to 50%, indicating that the utilization rate constraints exert little impact on the solutions under these situations, with the reason that the container demands can ensure at least 50% utilization rate for each train. From the second column, we can conclude that various values of parameter α will not influence the computation time dramatically.

(2) The train loading capacity relates to the number of container flatcars and required trains. Therefore, we analyze the relationship between the train loading capacity and the returned solution in the second set of experiments. In each experiment, the value of parameter C varies while the value of parameter α remains the same, which is 50%. Besides, for each train loading capacity, the maximum utilization rate that can be set is also computed. The corresponding results are displayed in Table 6.

Obviously, the train number increases gradually as the train loading capacity decreases, leading to the sharp growth of the computation time due to the increase of the number of variables and constraints. The flatcar number fluctuates with the change of train loading capacity, reaching its lowest point 175 when the parameter C takes the value of 70. From the fifth column, it is evident that there is negative correlation between the total number of stops and the train loading capacity. However, since some containers can be assigned to the extra trains, the average number of stops of each train has the positive feedback with the train loading capacity. For example, the average number of stops is 8 when the train loading capacity is set to 100, while the average number of stops drops to 7.2 when the train loading capacity falls to 60. Moreover, the maximum value that the parameter α can take varies with the train loading capacity. By comparing the second and third experiments or the fourth and fifth experiments, we can find that the maximum value of the parameter α increases but the train number remains the same. The reason is the redundant flatcars waste of train loading capacity. Last but not the least, from the point view of railway operators, the second decision strategy (i.e., the train loading capacity is set to 70) may be workable because the minimum flatcars are required and the maximum utilization rate of each train can be reached.

Considering the similarity between our model and the model in literature [20], a comparative analysis of the experiment results of the two papers is conducted. Firstly, both models optimize the stop plan with the detailed container (passenger)-to-train assignments. The experiments performed in literature [20] shows how the distribution plans influence the running distance of unoccupied seats because the train operation zones are addressed in their work. However, in this paper, we focus on the impact of distribution results on the train utilization rates since the passenger-like container trains should obey the law of freight transportation (i.e., only when the train utilization rates reach the standard, can trains be dispatched). Secondly, different values for the minimum utilization rate parameter α are set to test the influence of this parameter on the generated stop plans and container distribution plans, which is one of the distinct characteristics compared with their work. Finally, the experiments in two papers both test the influence of the maximum loading capacity of each train on the optimized solution, and the obtained results are similar. When the train loading capacity increases, the required train number will decrease and the total stops made by these trains will reduce. The reason is that the transportation organization process of container trains is the same as that of passenger trains, which is exactly the contribution (i.e., the concept of passenger-like container train is proposed) of our paper.

5. Conclusions

To the best of our knowledge, this is the first time that the concept of passenger-like container train is proposed. Based on the appropriate modification of railway yards, a passenger-like container train can halt at the intermediate stations without disintegration, which can increase the train frequency and containers demands compared with the traditional container through train.

To solve the correspondingly generated PLCTSPP, a mixed-integer linear programming model is formulated, where collaborative optimization for the stop plans and the container distribution plans can be achieved. In addition, the utilization rates of each individual train are considered in the proposed model. The Python language and CPLEX solver are adopted to solve the built model. A simple railway line and the Lianyungang-Alataw pass railway corridor are designed to implement the numerical experiments, which demonstrate the application of our model. The results also illustrate the relationship among stop plans, distribution plans, and train utilization rates.

Based on the concept of passenger-like container train, the railway container passenger-like transport system (RCPLTS) can be introduced, in which the passenger-like container trains are operated on a complex railway network. Therefore, our future research will focus on two major areas. First, the line plan of the RCPLTS should be solved to determine the line configuration, train frequency, and train stop plan. Second, we aim to optimize the timetable for RCPLTS to decrease the total transfer time.

Data Availability

The used container demands data are all assumed values. Although these values may not be completely accurate, they by no means affect us to test the model. Once provided, the accurate demand data can be brought into the model to obtain the solution.

Conflicts of Interest

The authors declare no conflicts of interest with respect to the research, authorship, and publication of this article.

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