Study on the Problems of Container Loading on Railroad Flatcar

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Abstract. The components of container loading problems on railroad flatcar were analyzed in this paper. The constraint conditions that needed to be considered when studying this problem were determined. A loading model was established which include objective function of flatcar length utilization. The Best Fit Algorithm was used for solving the model. The number of containers that cannot be loading with each container should be confirmed first according to railroad car loading technical constraints first, and then sort them by quantity. Finally, an example is used to implement the algorithm and the results indicated that the model and algorithm is feasible in practical application.

Introduction

Under the situation of rapid development of container transportation, it is an important problem must be considered that how to make rational use of railroad vehicles to transport containers in order to improve railway transportation efficiency and economic benefits. Containers loading on railroad flatcars is an important part of the container transportation process, which is the key to cost saving and efficiency improvement. Container loading problems can be divided into the following situations: different sizes of containers loading on flatcars, different weights of containers loading on flatcars and loading containers on different type of flatcars. The purpose of containers loading is to achieve maximum flatcars length and load utilization under transportation safety requirements.

Problem Description

The problem of containers loading on flatcars can be described as[1,2]: there are a certain number of containers need to be transported to destination in a railroad freight station. The containers need railroad flatcars and must be loaded according to Railroad Goods Loading and Securing Rules[3]. The containers loading order and position on the flatcars should be arranged reasonably. Under constraint conditions, the capacity utilization of flatcars should be maximized, and containers should be transported quickly and safely.

Problem Composition

The containers loading problem mainly includes container, railroad flatcar, loading technical rules, objective function and so on.

(1) Container

Containers are the object of loading. In general, consignor hand over containers to carrier for loading operations. The length of railroad containers in China are mainly 20ft and 40ft[4].

The size and weight of containers are the loading decision basis. Both of them need to meet the railroad flatcars technical rules. The total gravity center of the containers after loading should be within the reasonable range according loading rules.

(2) Flatcars

Flatcars are the containers transportation tools. The main technical parameters are flatcar weight, loading capacity, bogie center distance and length, etc. The main flatcars that can be loaded with containers are common flatcars and special flatcars. Common flatcars are $NX_{17AK}$, $NX_{17AT}$, $NX_{17K}$, $NX_{17T}$, etc. with loading capacity of 60t and $NX_{70}$, $NX_{70H}$, etc. with loading capacity of 70t. Special
Table 1. Flatcars technical parameters.

<table>
<thead>
<tr>
<th>Type</th>
<th>Weight [t]</th>
<th>Loading Capacity [t]</th>
<th>Bogie Center Distance [mm]</th>
<th>Flatcar Floor Length x Width [mm]</th>
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</thead>
<tbody>
<tr>
<td>NX_{17AK}</td>
<td>22.5</td>
<td>60</td>
<td>9000</td>
<td>13000 x 2980</td>
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<td>NX_{17AT}</td>
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<td>9000</td>
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<td>13000 x 2980</td>
</tr>
<tr>
<td>X_{6B}</td>
<td>22.4</td>
<td>60</td>
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<td>15400 x 2970</td>
</tr>
<tr>
<td>X_{6C}</td>
<td>20.2</td>
<td>60</td>
<td>10920</td>
<td>15400 x 3030</td>
</tr>
</tbody>
</table>

(3) Constraint Conditions
The constraint conditions that should be met during containers loading on flatcars includes:
1) Containers’ type, size, quantity;
2) Containers loading directions on flatcars (For example, two containers on the same flatcar must be loaded door-to-door);
3) Single deck loading;
4) The total containers weight on a flatcar must be within the loading capacity, the size of containers must meet the flatcar’s requirements.
5) Each flatcar has two bogies. The loading on each bogie must not exceed half of the flatcars loading capacity, and the loading difference between two bogies must not exceed 10t[5].

(4) Objective Function
The expected target of the containers loading plan is to make the highest flatcar length utilization, which means using the minimum number of flatcars for loading containers.

Loading Model
There are m containers in a railroad freight station need to be transported, the number of containers are 1,2,3…n,n+1…m, numbers 1 to n are 20ft containers, numbers n+1 to m are 40ft containers. Containers’ weight are $W_1,W_2,W_3…W_m$. The distance from the gravity center of each container to its door is $d_i$. The number of flatcar type is F, the number of flatcars per type are $N_1,N_2,…,N_F$. The flatcars’ allowed loading length are $L_1,L_2,…,L_F$. Bogie Center Distance of each type of flatcar are $S_1,S_2,…,S_F$, loading capacity are $Z_1,Z_2,…,Z_F$. $num$ is the flatcars quantity. $x_{ij}$ is the quantity of container $i$ on flatcar $j$, it is 0-1 variable. Longitudinal allowable deviation of combined containers’ gravity center after loading on flatcar $j$ is $a_j$. The total weight of containers on flatcar $j$ is $Q_j$.

(1) Loading length constraint
\[
\sum_{i=1}^{m} x_{ij} L_j + (\sum_{i=1}^{m} x_{ij} - 1) D \leq L_j
\]

$D$ is the minimum spacing between adjacent containers, (m).

(2) Flatcar loading capacity constraint
\[
\sum_{i=1}^{m} x_{ij} W_i \leq Z_j
\]

(3) Longitudinal deviation of combined containers’ gravity center constraint

*Railroad Goods Loading and Securing Rules* has requirements that the loading on each bogie must not exceed half of the flatcars loading capacity, and the loading difference between two bogies must not exceed 10t. Longitudinal deviation of combined containers’ gravity center can be calculated as,

When $Z_j - Q_j < 10$
\[ a_i = \left( \frac{Z_i}{Q_i} - 0.5 \right) S_i \]  
When \( Z_i - Q_i \geq 10 \)  

(3)

\[ a_j = \frac{5}{Q_j} S_j \]  

(4)

Longitudinal deviation of combined containers’ gravity center is:

\[ a_j^* = \left[ \sum_{i=1}^{n} Y_{i,j} W_{i,j} / \sum_{i=1}^{n} W_{i,j} - L_j / 2 \right] \]

(5)

\( W_{i,j} \) is the No.\( i \) container’s weight on flatcar \( j \), [t]. \( Y_{i,j} \) is the distance between gravity center of No.\( i \) container and the front end of the flatcar \( j \).

\[ Y_{i,j} = \sum_{i=1}^{n} l_{j,i} + (t-1)D + d_{j,i} + e_j \]  

(6)

\( l_{j,i} \) is the length of No.\( r \) container on flatcar \( j \), [t]. \( d_{j,i} \) is the distance between gravity center of No.\( i \) container and the container door on flatcar \( j \), [m]. \( e_j \) is the distance between the front end of No.1 container and the front end of the flatcar \( j \), (m).

\[ e_j = \left[ L_j - \sum_{i=1}^{n} l_{j,i} -(n(j)-1)D \right] / 2 \]  

(7)

The objective function of flatcar length utilization,

\[ \text{max } f(x) = \frac{\sum_{j=1}^{n} l_j}{\sum_{j=1}^{n} L_j} \times 100\% \]  

(8)

**Best Fit Algorithm**

*Best Fit Algorithm* is a method to find out the smallest size of free place from all the free areas, which can meet the requirements of operation. This method can make useless space as small as possible[6].

*Best Fit Algorithm* can be applied to the problem of container loading for the purpose of saving flatcars. For this problem, the following improvements can be made.

Step1: List the unmatched container number of container \( i \) according to container loading table, regarded as set \( D_i \). \( R_i \) is the number of elements in set \( D_i \), regarded as repulsion degree. For example, \( D_1 = (4, 6) \) means No.1 container cannot be fitted on the same flatcar with containers No.4 and No.6, \( R_1 = 2 \).

Step2: Array \( R_i \) in descending order.

Step3: Loading the container which has the biggest \( R_i \) in the unloaded containers.

Step4: Judging the flatcar is loading full or not, if not, looking for the container which has the biggest \( R_i \) in the containers can be matched to it, then, loading them on the same flatcar.

Step 5: Repeat Step3 and Step4 until all containers are loaded.

**Example**

There are 45 containers need to be transported to the same destination, including 9 40ft containers and 36 20ft containers. \( NX_{17K} \) flatcar will be used. Table 2 & 3 includes the container weight, gravity center position (the distance between gravity center and container door). Solving the economical and reasonable loading plan.
Table 2. 20ft containers.

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Table 3. 40ft container.

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<tr>
<td>Weight[t]</td>
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According to Best Fit Algorithm, list the unmatched sets $D_i$ of 20ft container $i$,

$D_1$=0, $D_2$=0, $D_3$=0, $D_4$=0

$D_5$=(11,12,14)                              $R_5$=3

$D_6$=(10,11,12,14,19,30,31)                    $R_6$=7

$D_7$=(10,11,12,14,19,30,31)                    $R_7$=7

$D_8$=(12, 14)                                $R_8$=2

$D_9$=0

$D_{10}$=(6,7,15,17,21,34,35)                   $R_{10}$=7

$D_{11}$=(5,6,7,15,17,18,20,21,22,26,29,34,35)  $R_{11}$=13

$D_{12}$=(5,6,7,8,15,17,18,20,21,22,25,26,29,34,35)  $R_{12}$=15

$D_{13}$=(21,35)                               $R_{13}$=2

$D_{14}$=(5,6,7,8,15,17,18,20,21,22,25,26,29,34,35)  $R_{14}$=15

$D_{15}$=(10,11,12,14,30)                      $R_{15}$=5

$D_{16}$=0

$D_{17}$=(10,11,12,14,30,31)                   $R_{17}$=6

$D_{18}$=(11,12, 14)                           $R_{18}$=3

$D_{19}$=(6,7,35,21)                           $R_{19}$=4

$D_{20}$=(11,12, 14)                           $R_{20}$=3

$D_{21}$=(10,11,12,13,14, 19,23,24,30,31,36)   $R_{21}$=11

$D_{22}$=(11,12, 14)                           $R_{22}$=3

$D_{23}$=(21,35)                               $R_{23}$=2

$D_{24}$=(21,35)                               $R_{24}$=2

$D_{25}$=(12,14)                               $R_{25}$=2

$D_{26}$=(11,12, 14)                           $R_{26}$=3

$D_{27}$=0

$D_{28}$=0

$D_{29}$=(11,12,14)                           $R_{29}$=3

$D_{30}$=(6,7,15,17,21,34,35)                   $R_{30}$=7

$D_{31}$=(6,7,17,21, 34,35)                     $R_{31}$=6

$D_{32}$=0

$D_{33}$=0

$D_{34}$=(10,11,12,14,30, 31)                  $R_{34}$=6

$D_{35}$=(10,11,12,13,14,19,23,24,30,21,36)    $R_{35}$=11

$D_{36}$=(21, 35)                               $R_{36}$=2

Array the containers according to $R_i$ in descending order. The 20ft containers order is 12, 14, 11,
First loading the container which has the biggest $R_i$, the loading result is (12, 14) (11, 10) (21, 35) (6, 7) (30, 31) (17, 34) (15, 19) (20, 22) (26, 29) (8, 13) (23, 24) (25, 36) (1, 2) (3, 4) (9, 16) (27, 28) (32, 33).

The loading plan needs $18 \times 17K$ flatcars for loading 20ft containers, $9 \times 17K$ flatcars for loading 40ft containers.

**Conclusion**

Based on the actual situation in China, containers loading on flatcar is the analyzed problem, the constraint conditions were confirmed and loading model was established. The validity and practicability of the model and algorithm were validated by an example. For railroad flatcars which can be loaded with two 20ft containers, the best loading plan can be obtained by *Best Fit Algorithm*.

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**References**


