Optimization of Traffic Organization of loading ground based on transport loss

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Abstract. From the point of view of the railway company, the consignor and consignor to establish a cost optimization target system to study the loading area traffic organization optimization problem. Considering the transportation cost of the railway company and the cargo delivery side of the transport loss, this paper combines different characteristics of different cargo vulnerability and constructs a loading area traffic organization optimization model to minimize the total cost of the integrated economy. Finally, a corresponding example is given, and the model is solved by using LINGO software.

1. Introduction

With the continuous expansion of the scale of the current railway network, railway transportation will be further developed. Considering the advantages of railway freight transportation, such as large volume, low cost, accurate arrival and departure time, railway transportation will be the first choice for the transportation of coal, oil, grain, aquatic products and other bulk goods. However, for different types of bulk goods, the transportation loss is different in the transportation process. We should combine the different loss characteristics of them to organize the relevant traffic as reasonably as possible, and establish a reasonable traffic organization scheme to ensure its reasonable and efficient transportation.

For the train flow organization, experts and scholars at home and abroad have done a lot of analyses and research, and achieved fruitful results. In the existing research fields, Literature [1] is the first study to use the systematic idea to put forward the "simultaneous calculation method" to optimize the traffic flow operation scheme of technical station. It established a model containing the information of train flow reorganization information in technical station, and the decision variable of the model is whether to organize direct freight trains or not. Literature [2] fully combines the necessary conditions and parameter selection for organizing the through train. It constructs a non-linear 0-1 programming model of the marshalling plan of the loading area, has a better description of the various combinations of the operation schemes of the starting train flow, and comprehensively analyzes the theoretical problems in many aspects of the marshalling plan of the loading area. Literature [3] and [4] consider both transportation cost and inventory cost, take the minimum cost of logistics system as the objective function at the same time, construct a non-linear 0-1 programming model for the direct freight train operation scheme in the loading area to determine the optimal scheme of train operation at the loading area. Literature [5] from the perspective of network flow and combination optimization, studies the comprehensive optimization problems of technical through (direct) marshalling plan, marshalling plan of through train in loading area of road network and train
operation plan within district. Based on the OD traffic flow between the original stations, it deeply analyzes the advantages and disadvantages of operating section train, so as to build a comprehensive optimization model of direct to loading site, technical direct and district train formation plan. Finally, a numerical example is used to obtain the traffic organization optimization plan of minimum relative consumption of car-hour. Through comparative analysis, the rationality and necessity of bringing the operation conditions of district trains into the comprehensive optimization of train formation plan are verified. Literature [6] analyzes the categories, favorable indexes, operation conditions and scheme determination of the railway freight through train, and constructs the mathematical model of the marshalling plan of the direct transportation.

2. Problem description
The railway department generally takes the shortest operation car-hour as the optimization goal when preparing the train operation plan. The formulation of the train operation plan is considered from the perspective of the minimum transportation cost of the railway department. With the rapid development of society and economy, the competition among enterprises is becoming more and more fierce. In order to better adapt to the market demand, the railway department needs to optimize the plan from the overall interests of the consignee, consignor and railway department when preparing the train operation plan, so as to reduce the comprehensive cost of the whole logistics system to maximize the overall benefit.

The delivery of goods from the loading place to the unloading place must go through the delivery, transportation and receiving links. Each link will involve the respective interests of the consignor, the carrier and the consignee. Therefore, the target of the optimization of direct freight train schemes for loading area should be composed of the costs of the consignor, the carrier and the consignee. Among them, due to the different types of goods of the consignor and the consignee, the loss in the transportation is also different. For example, the loss of aquatic products, fruits and vegetables is far greater than the loss of coal and oil. Therefore, on the basis of the possibility and rationality of organizing the direct train at the loading place, the transportation loss of different goods shall be fully considered. With the goal of minimizing the total logistics cost, a 0-1 planning model of direct train operation scheme at the loading place is established. So as to provide a set of alternatives for the formulation of a reasonable organization scheme of traffic flow in the loading area, and finally realize the maximization of the interests of the railway company and customers.

3. Model construction

3.1. The Introduced Parameters are as follows:

- \( N_{st} \): average daily traffic volume from loading site ‘s’ to unloading site ‘t’.
- \( \omega_{st}^{d} \): The consumption of car-hour of each vehicle of the initial departure traffic flow leaving the loading area in a direct way.
- \( \omega_{st}^{n-d} \): The consumption of car-hour of each vehicle of the initial departure traffic flow leaving the loading area in a non direct way.
- \( \omega_{stul}^{d} \): The consumption of car-hour of each vehicle of the initial departure traffic flow entering the unloading area in a direct way.
- \( \omega_{stul}^{n-d} \): The consumption of car-hour of each vehicle of the initial departure traffic flow entering the unloading area in a non direct way.
- \( t_{i} \): The average consumption of car-hour of each vehicle of the reorganization in station ‘i’ of the non direct train of the initial departure traffic flow deducting the average consumption of car-hour of each vehicle of direct train of the initial departure traffic flow without reorganization.
- \( m_{st} \): The maximum vehicle number of dense loading and unloading allowed in the initial departure traffic flow.
- \( \bar{m}_{st} \): The average number of vehicles in the initial departure traffic flow.
3. The economic loss of the goods owner caused by the delay of one hour for each vehicle in different initial departure traffic flow.

\( \gamma \): Loss equivalent, the economic loss per hour of each vehicle converted into parking car-hour.

\( V \): The collection of technical stations on the road network.

\( V(s) \): The collection of technical stations adjacent to the loading site.

\( Q(s) \): The collection of all unloading places of the traffic flow started from the loading place ‘s’.

\( V(k,t) \): The collection of technical stations to be reorganized along the way, and it is agreed that ‘k’ station is included in \( V(k,t) \).

3.2. Decision Variables

1. \( x_{st} \) = {1 \text{ If the traffic flow operates the direct train from loading site to unloading site}} 0 \text{ else}

2. \( x_{st}^k \) = {1 \text{ If the first reorganization station of Nst is ‘k’}} 0 \text{ else}

3. \( I_{st} \) = {1 \text{ If } m_{st} \geq \bar{m}_{st}} 0 \text{ else}

3.3. Objective Function

When the initial departure flow ‘N_{st}’ is a large train flow, the consumption of car-hour of the direct train from the loading place to the unloading place is:

\[ Z_1 = N_{st}x_{st}(\omega_{stl}^d + \omega_{stul}^d) \quad (1) \]

When the initial departure train flow ‘Nst’ is sent to the nearest technical station in front operated as the technical train flow, the converted consumption of car-hour generated at the loading place and unloading place is:

\[ Z_2 = N_{st}x_{st}^k(\omega_{stl}^{n-d} + \omega_{stul}^{n-d}), k \in V(s) \quad (2) \]

The initial departure train flow ‘Nst’ is sent to the adjacent technical station in front operated as the technical train flow. The consumption of car-hour of the train for operation in the technical station and the loss of goods during transportation:

\[ Z_3 = N_{st}x_{st}^k \sum_{i \in V(k,t)} t_i (1 + L_{st}\gamma), k \in V(s) \quad (3) \]

When the initial departure train flow ‘Nst’ is sent to the non adjacent technical station in front operated as the technical train flow, the converted consumption of car-hour generated at the loading place and unloading place is as follows:

\[ Z_4 = N_{st}x_{st}^k(\omega_{stl}^{d} + \omega_{stul}^{n-d}), k \in V \setminus V(s) \quad (4) \]

When the initial departure train flow ‘Nst’ is sent to the non adjacent technical station in front operated as the technical train flow, the consumption of car-hour of the train for operation in the technical station and the loss of goods during transportation:

\[ Z_5 = N_{st}x_{st}^k \sum_{i \in V(k,t)} t_i (1 + L_{st}\gamma), k \in V \setminus V(s) \quad (5) \]

Therefore, the total consumption of train flow on the way is:

\[ Z = \sum_{i=1}^{5} Z_i \quad (6) \]

3.4. Constraints

There are three ways for the initial departure flow to be transported from the loading place to the unloading place:

- Organize the operation of direct trains from loading place to unloading place.
- Organize the operation of the direct train from the loading place to the non adjacent technical station in front, and merge into the corresponding technical flow after the technical station is reorganized.

\( L_{st} \): The economic loss of the goods owner caused by the delay of one hour for each vehicle in different initial departure traffic flow.

\( \gamma \): Loss equivalent, the economic loss per hour of each vehicle converted into parking car-hour.

\( V \): The collection of technical stations on the road network.

\( V(s) \): The collection of technical stations adjacent to the loading site.

\( Q(s) \): The collection of all unloading places of the traffic flow started from the loading place ‘s’.

\( V(k,t) \): The collection of technical stations to be reorganized along the way, and it is agreed that ‘k’ station is included in \( V(k,t) \).
• Organize the operation of the direct train from the loading place to the adjacent technical station in front, and merge into the corresponding technical flow after the technical station is reorganized.

Therefore, the uniqueness condition of the scheme of \( N_{st} \) organization of traffic flow is as follows:

\[
I_{st}x_{st} + \sum_{k \in \mathcal{V}} x_{st}^k = 1 
\]  
(7)

\( I_{st} \) is to meet the necessary conditions of the traffic (large stocks of traffic) open line direct unloading of the train.

The allowable dense loading number \( m_{st} \) of the initial departure flow \( N_{st} \) is:

\[
m_{st} = \min\{m_{st}^L, m_{st}^U\} 
\]  
(8)

In the formula, \( m_{st}^L \) is the number of allowed dense loading of traffic flow \( N_{st} \); \( m_{st}^U \) is the number of allowed dense unloading of traffic flow \( N_{st} \).

For the large train flow, i.e. the train flow of \( m_{st} \geq m_{st} \) (here refers to the situation that the daily average planned train flow can meet the requirement of organizing the direct train independently), the direct train shall be organized separately. For the small train flow, i.e. the train flow with \( m_{st} < m_{st} \), it should be considered whether to combine with other train flows to operate the direct train. When a initial departure direct train operated from loading place \( s \) to a fulcrum station \( K \), the total number of allowed dense loading and unloading vehicles of each flow attracted by the direct train destination shall meet the necessary conditions:

\[
m_{st} I\left(\sum_{t} x_{st}^k\right) - \sum_{t} m_{st} x_{st}^k \leq 0 
\]  
(9)

In the formula: \( I(x) \) is a step function, defined as:

\[
I(x) = \begin{cases} 
1, & x > 0 \\
0, & x \leq 0 
\end{cases} 
\]  
(10)

Because this is a nonlinear 0-1 programming model. In order to solve the model conveniently, it is linearized here. May order:

\[
x_{sk} = I\left(\sum_{t} x_{st}^k\right) = \begin{cases} 
1, & \text{there is a direct train from loading station } s \text{ to technical station } k \\
0, & \text{others} 
\end{cases} 
\]  
(11)

Bring the formula in, then we can get:

\[
\overline{m}_{st}x_{sk} - \sum_{t} m_{st} x_{st}^k \leq 0 
\]  
(12)

As long as \( x_{st}^k > 0 \), there must be \( x_{sk} = 1 \). Therefore, a set of constraints should be added accordingly after introducing the variable \( x_{sk} \):

\[
x_{sk} \geq x_{st}^k 
\]  
(13)

Using the characteristics of 0-1 variables, this set of constraints is superposed, and the result is as follows:

\[
M x_{sk} - \sum_{t} x_{st}^k \geq 0 
\]  
(14)

In summary, the model can be converted to the following linear 0-1 planning form:

\[
\begin{align*}
\text{Min} & \quad Z = \sum_{i=1}^{5} Z_i \\
\text{s.t.} & \quad I_{st}x_{st} + \sum_{k \in \mathcal{V}} x_{st}^k = 1 \quad \forall t \in \mathcal{Q}(s) \\
& \quad \overline{m}_{st} I\left(\sum_{t} x_{st}^k\right) - \sum_{t} m_{st} x_{st}^k \leq 0 \quad k \in \mathcal{V}\setminus\mathcal{V}(s) \\
& \quad M x_{sk} - \sum_{t} x_{st}^k \geq 0 \quad k \in \mathcal{V}\setminus\mathcal{V}(s) \\
& \quad \sum_{t} y_{ij}^l = 0 \quad \forall i, j \\
& \quad x_{st}, x_{st}^k, x_{sk} \in \{0,1\}
\end{align*}
\]
4. Calculating examples

A simple road network structure diagram is given here, as shown in Figure 1 below, where 1 represents the loading station of the departure station, 2-9 represent the technical station on the way, and 10-14 represent the unloading station of the terminal station.

Figure 1 Network structure

4.1. The relevant data and parameters

Table 1 Traffic OD data

| Car flow | Cars number | Consumption | Consumption |
|----------|-------------|-------------|-------------|
| N_{10}   | 100         | 100         | 0.1         |
| N_{11}   | 12          | 12          | 1.8         |
| N_{12}   | 32          | 32          | 0.3         |
| N_{13}   | 30          | 30          | 1.9         |
| N_{14}   | 42          | 42          | 1.2         |
| N_{15}   | 53          | 53          | 1.1         |
| N_{16}   | 34          | 34          | 0.7         |

4.2. Technical parameters of each technical station

Table 2 Technical station parameter

| Technical Station Number | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 2 |
|--------------------------|---|---|---|---|---|---|---|---|---|
| Technical station reoperation consumption t_i | 5 | 3 | 4 | 3 | 4 | 4 | 5 | 5 | 5 |
| m_{st} | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 |

4.3. Other parameters

The cost of loading and unloading is as follows:

\[ \omega_{st_1}^{d} = 10, \quad \omega_{st_1}^{n-d} = 15, \quad \omega_{stUL}^{d} = 8, \quad \omega_{stUL}^{n-d} = 18. \]

4.4. Example model

To simplify the calculation, this example shows a linear road network structure with only one loading place. Therefore, only the unloading place is marked for the initial departure flow, and the underground loading mark is omitted. The example model is shown as follows:

\[ \text{Min} = C_{10} + C_{11} + C_{12} + C_{13} + C_{14} + C_{15} + C_{16} \]

In the objective function, the expressions of \( C_{10}, C_{11}, C_{12}, C_{13}, C_{14}, C_{15}, C_{16} \) are respectively as follows:
\[\begin{align*}
C_{10} &= N_{10} \left[ w_{10}^d + w_{10a}^d \right] x_{10} + \left[ w_{10}^d + w_{10a}^d + \sum_{i=V(2,10)} t_i (1 + L_{10}) \right] x_{10}^2 + \left[ w_{10}^d + w_{10a}^d + \sum_{i=V(3,10)} t_i (1 + L_{10}) \right] x_{10}^3 \\
C_{11} &= N_{11} \left[ w_{11}^d + w_{11a}^d \right] x_{11} + \left[ w_{11}^d + w_{11a}^d + \sum_{i=V(2,11)} t_i (1 + L_{11}) \right] x_{11}^2 + \left[ w_{11}^d + w_{11a}^d + \sum_{i=V(3,11)} t_i (1 + L_{11}) \right] x_{11}^3 \\
C_{12} &= N_{12} \left[ w_{12}^d + w_{12a}^d \right] x_{12} + \left[ w_{12}^d + w_{12a}^d + \sum_{i=V(2,12)} t_i (1 + L_{12}) \right] x_{12}^2 + \left[ w_{12}^d + w_{12a}^d + \sum_{i=V(3,12)} t_i (1 + L_{12}) \right] x_{12}^3 \\
C_{13} &= N_{13} \left[ w_{13}^d + w_{13a}^d \right] x_{13} + \left[ w_{13}^d + w_{13a}^d + \sum_{i=V(2,13)} t_i (1 + L_{13}) \right] x_{13}^2 + \left[ w_{13}^d + w_{13a}^d + \sum_{i=V(3,13)} t_i (1 + L_{13}) \right] x_{13}^3 \\
C_{14} &= N_{14} \left[ w_{14}^d + w_{14a}^d \right] x_{14} + \left[ w_{14}^d + w_{14a}^d + \sum_{i=V(2,14)} t_i (1 + L_{14}) \right] x_{14}^2 + \left[ w_{14}^d + w_{14a}^d + \sum_{i=V(3,14)} t_i (1 + L_{14}) \right] x_{14}^3 \\
C_{15} &= N_{15} \left[ w_{15}^d + w_{15a}^d \right] x_{15} + \left[ w_{15}^d + w_{15a}^d + \sum_{i=V(2,15)} t_i (1 + L_{15}) \right] x_{15}^2 + \left[ w_{15}^d + w_{15a}^d + \sum_{i=V(3,15)} t_i (1 + L_{15}) \right] x_{15}^3 \\
C_{16} &= N_{16} \left[ w_{16}^d + w_{16a}^d \right] x_{16} + \left[ w_{16}^d + w_{16a}^d + \sum_{i=V(2,16)} t_i (1 + L_{16}) \right] x_{16}^2 + \left[ w_{16}^d + w_{16a}^d + \sum_{i=V(3,16)} t_i (1 + L_{16}) \right] x_{16}^3
\end{align*}\]

S.T

\[\begin{align*}
I_{10} x_{10} + x_{10}^2 + x_{10}^3 &= 1 \\
I_{11} x_{11} + x_{11}^2 + x_{11}^3 &= 1 \\
I_{12} x_{12} + x_{12}^2 + x_{12}^3 + x_{12}^4 &= 1 \\
I_{13} x_{13} + x_{13}^2 + x_{13}^3 + x_{13}^4 + x_{13}^5 &= 1 \\
I_{14} x_{14} + x_{14}^2 + x_{14}^3 + x_{14}^4 + x_{14}^5 + x_{14}^6 &= 1 \\
I_{15} x_{15} + x_{15}^2 + x_{15}^3 + x_{15}^4 + x_{15}^5 + x_{15}^6 + x_{15}^7 &= 1 \\
I_{16} x_{16} + x_{16}^2 + x_{16}^3 + x_{16}^4 + x_{16}^5 + x_{16}^6 + x_{16}^7 + x_{16}^8 &= 1
\end{align*}\]
The results obtained are as follows: $x_{10} = 1$, $x_{14} = 1$, $x_{15} = 1$, $x_{11}^0 = 1$, $x_{12}^0 = 1$, $x_{13} = 1$, $x_{16}^0 = 1$. The other variables are all 0, and the cost of this scheme is 6306 car-hour. The corresponding traffic organization scheme is shown in Figure 2 below:

![Figure 2 Traffic Organization programme](image)

In the figure above, the trains that arrive at 10, 14 and 15 unloading stations and arrive at other unloading stations will be reorganized and delivered. Among them, the trains that arrive at 11 and 12 unloading stations will be reorganized at 9 technical station on the way, and the trains that arrive at 13 and 16 unloading stations will be reorganized at 6 technical station on the way.

5. Summary

For the transportation of railway bulk goods, different forms of train flow organization will produce different transportation and loading costs. Different types of goods can bring different transportation loss costs. Based on the point-to-point transportation organization, this paper analyzes the conditions of the point-to-point direct trains, establishes the point-to-point optimization organization model, selects the point-to-point direct trains or other forms of trains according to their different restrictions, and finally gives the relevant examples for analysis, thus verifying the feasibility of the model.

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