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Path Optimization Study of LNG Tanker Resource Allocation in Multi-transportation Mode

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Abstract

In order to solve the rational allocation of LNG tank resources, the objective function model of minimizing transportation cost is constructed by considering the tank cost, storage cost, maintenance cost, and management cost in the multimodal transportation network, and introducing the penalty function to characterize the influence of uncertainty factors, and solved by using CPLEX optimization software. The solution results of the case considering the reasonable allocation of LNG tanker resources show that the allocation of LNG tanker resources affects the choice of different transportation modes, and the "water-rail-road" transportation mode is the most economical transportation solution to cope with the variable LNG tanker resources. The model can be used to select the optimal transportation mode for the complex and variable LNG tanker resource allocation, which provides a certain reference basis for the operation of LNG operating enterprises and promotes the development of the LNG industry.

Keywords

Multimodal Transport; Route Optimization; CPLEX Optimization; LNG Tanker Resources.

1. Introduction

Based on the tank container import multimodal logistics mode, easy storage, and transportation, easy sea, and land, safe and environmentally friendly, while having good flexibility, the tank container is the storage and transportation tools throughout, reasonably equipped with tank containers become the key to the smooth operation of the network. Unlike other modes of transport such as pipeline transport, as long as the line is laid, the ship loaded with cargo can safely reach the loading and unloading terminal, trade can be smoothly fulfilled. For tank container mode, if there is no considerable tank container, the whole downstream industrial chain can not run smoothly, if the tank container allocation is too much and will bring social resources waste and enterprise cost pressure, so reasonable optimization of the amount of tank container allocation is the key to the construction of the downstream industrial chain of imported resources. At the same time, based on reasonable optimization of resource allocation, choose the lowest cost transportation mode is an important issue of concern to the business operators.

Janic (2007) constructed a planning model intending to minimize the total cost based on the consideration of internal and external costs of transportation in multimodal mode and thus designed an algorithm to solve for the optimal route [1]. Ziliaskopoulos and Wardell (2000) constructed a planning model intending to minimize the total time based on time considerations for multimodal transport modes and designed an algorithm to solve for the optimal route [2]. Lozano and Storchi (2001) considered the transportation cost and the number of transshipment in multimodal transport mode, constructed a dual objective function, and set different weights for the two objectives for decision-makers to choose, and used the labeling method to solve the shortest path in the solution process [3]. Yang et al. (2015) established a technical route map for natural gas hydrate storage and

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transportation using LNG technology, showing that LNG technology is more economical than pipeline technology and proposing a new idea of using LNG technology to store and transport hydrates [4].

The LNG logistics mode based on tank container, while having many advantages such as "suitable for sea and land", "suitable for storage and transportation" and "one tank to the end", can connect different modes of transportation. It can realize the "door-to-door" distribution business. On the one hand, because LNG logistics mode with tank container as carrier belongs to the dangerous goods transportation, it is restricted by many factors in the process of multimodal transportation, such as the influence of the remaining non-destructive maintenance time of tank container on safe transportation; on the other hand, unlike ordinary container, tank container has a high cost and requires dangerous goods container yard for storage of heavy and empty containers, which brings higher logistics cost. In summary, the safe and efficient operation of the tank container becomes the key to ensure supply and reduce logistics costs. Based on the above considerations, this paper takes into account the tank cost, storage cost, maintenance cost, and management cost in the multimodal transportation network, and introduces a penalty function to characterize the impact of uncertainties to build an objective function model for minimizing transportation cost, which provides a theoretical reference basis for LNG operating enterprises to select transportation mode.

2. Problem Description and Modeling

2.1 Problem Description

In order to ensure that the tank containers are stored and transported without damage, this paper focuses on the route optimization problem in a three-level multimodal network consisting of multiple LNG supply points - multiple distribution centers - multiple customers. In the schematic diagram of the multimodal network shown in Fig. 1, LNG tanks need to be transported from supply points (s1, s2, s3, s4, s5, s6) to demand points (c3, c4, c5).

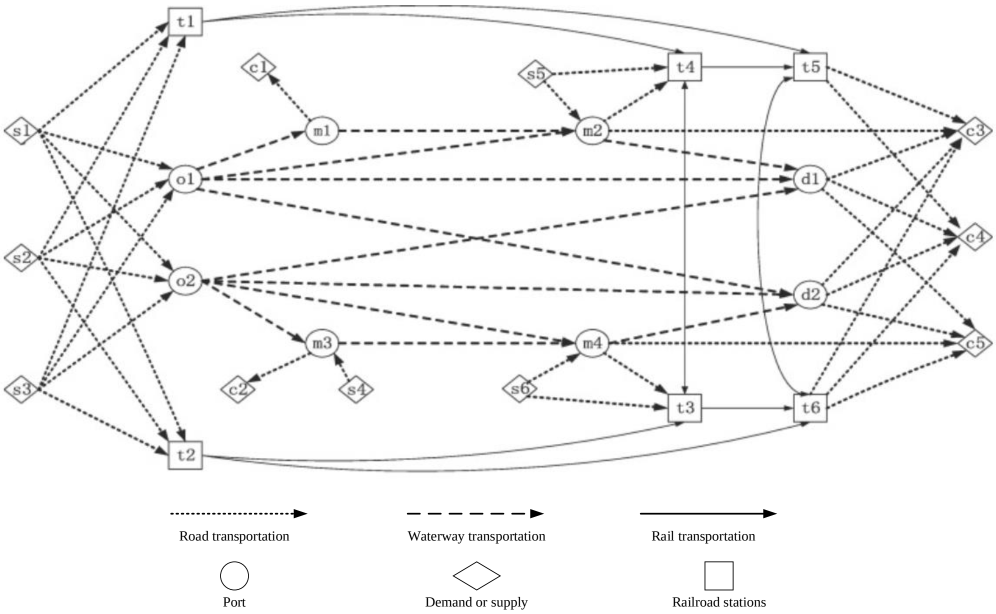

Fig. 1 The schematic diagram of the multimodal network

Based on the tank container import land logistics mode, tank container equipped with the problem is to ensure that the import tank container mode meets the needs of the premise of optimizing the tank container flow between the nodes to achieve the goal of minimizing the system logistics costs or maximize profits. Import land tank container mode optimization, the core of which is to solve the following two problems.

(1) The number of tank container totes to ensure a safe transfer

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Under the premise of meeting demand, reasonably equipped with tank containers equipped with the amount of reasonable turnover, reduce costs, to protect imported resources land-based tank container logistics mode of safe transfer.

(2) Optimal scheduling solution for tank containers to ensure safe shipment

Under the premise of guaranteeing the safe resource transfer, the tank container optimal scheduling plan includes three aspects, one is the optimal scheduling route, i.e. the transfer route of the tank container from the supply place to the demand place; the second is the transfer time, the system tank container weekly container volume transfer should meet the system demand, the vehicle operation should also try to improve the vehicle operation efficiency and guarantee the tank container turnover efficiency; the third is the transfer container volume, i.e. Determine the number of tank containers transferred between the demand and supply places.

Based on the tank container import multimodal logistics mode, tank container allocation volume optimization research is from the point of view of the entire system, research in the case of certain consumer demand, the entire industry chain should be configured how many tank containers to meet the flow of demand, and how to transfer between the terminal nodes to achieve the maximum use of the tank container, to ensure that the tank container in the import downstream industry chain The balanced operation.

2.2 Modeling

2.2.1 System Assumption

(1) The supply and demand of tank boxes are known at each node for a certain period.

(2) Consider only one box type, i.e. 40 feet.

(3) The phenomenon of transshipment is not considered, and there is a safe storage time limit for LNG loaded in tank containers, and the phenomenon of transshipment is not considered.

(4) Tank containers do not incur additional dwell time at the point of supply, i.e. the LNG supply point, and are converted directly into heavy-duty tank containers that are not mobilized earlier to the demand node.

(5) Storage costs if tank containers are not mobilized on time.

(6) Tank container shipment decision period is: T days, the decision interval is calculated in T days;

(7) If the time between two of the nodes for a particular mode of transportation is greater than the decision interval, then it indicates that the mode of transportation is not feasible.

(8) The demand for tank containers at LNG supply points must be met.

(9) Tank containers must be emptied within the decision period or returned to the LNG supply point for safety;

(10) The vehicle fully meets the tank container transfer time and transfer volume, and the vehicle transfer cycle is known.

(11) Assume that all tank containers are newly built, with known maintenance intervals and known scrap rates.

(12) The various transfer costs involved in the tank container logistics model are known.

2.2.2 System Assumption

Decision variables:

X_{ijk} denotes the number of LNG tank containers selected transportation mode k for transfer from node i to node j. Unit: TEU.

Parameter meaning:

P indicates the unit price, the cost of construction of the LNG tank container. Unit: RMB.

Q indicates the total number of containers configured for the system. Unit: TEU.

q denotes the number of containers per set, which is related to the ship's carrying capacity. Unit: TEU.

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S denotes a collection of LNG supply points.

D denotes the set of LNG demand points.

N denotes the set of all transport route types.

t_h indicates the sailing time of a ship in sea transportation. Unit: days.

t_n indicates the shift period. Unit: days.

t_a indicates the inland transit time of the container in the port of origin. Unit: days.

t_d indicates the inland transit time of the container in the port of arrival. Unit: days.

t_s indicates the safety time of LNG storage and transportation in tank containers. Unit: days.

C_{ijk} denotes the cost of choosing transportation mode k from node i to node j.

C_w denotes the storage cost of the LNG tank container. Unit: RMB per day.

C_M denotes the management cost of a single LNG tank container. Unit: RMB per day.

ω denotes the weighting effect of the uncertainty factor.

F indicates that the penalty function is considered.

2.2.3 Objective Function and Constraints

The objective function is the total cost spent by the owners and users of the tank containers in the system. The total cost includes the purchase cost of buying from the tank container, the cost of shipping and land transportation in multimodal mode, the cost of storage at the supply point and the user, certain maintenance costs and other related costs, and the opportunity cost. Where, F is the probability distribution function of inland transit time, which conforms to the exponential distribution and is a statistical law.

$$\min Z = P \cdot Q + \sum_{i\in S}\sum_{j\in D}\sum_{k\in N} X_{ijk} \cdot C_{ijk} + \sum_{i\in S}\sum_{j\in D}\sum_{k\in N} X_{ijk} \cdot C_w + \sum_{i\in\forall,k\in\forall,j\in D} X_{ijk} \cdot C_B + C_M + \omega \cdot F \quad (1)$$

S.T.

$$\textstyle\sum_{\forall k} X_{ijk} = X_{sd} \quad (2)$$

$$\textstyle\sum_{k\in N} X_{ijk} = \sum_{k\in N} X_{jik} \quad (3)$$

$$t_h/2 + t_a + t_d \le t_s \quad (4)$$

$$Q = q\,\frac{(t_h + max(t_d) + t_a)}{t_n} \quad (5)$$

$$\textstyle\sum_{\forall k} X_{sd} \le q \quad (6)$$

Constraint (2) indicates that the tank container should ensure the balance of supply and demand, while the container allocation quantity should meet the freight demand of downstream customers, timely, accurate, and safe delivery to ensure the production and operation of the downstream industry chain; constraint (3) indicates that to ensure the balanced operation of the system, at each demand point, the number of incoming tank containers is equal to the number of outgoing tank containers; constraint (4) indicates that the tank container The constraint of inland turnaround time. Constraint (5) indicates the total number of allocated containers. The resources will eventually be transported to the consumption terminal for consumption by various modes of transportation, so the tank container allocation is equal to the transportation volume transported to the consumption terminal by various modes of transportation. Constraint (6) indicates that the tank container transfer volume should be less than the rated cargo capacity of LNG vessels.

As shown in Table 1, the tank container single box construction cost of 640,000 RMB the cost of expensive, the internal rate of return of the enterprise for 15% benchmark, calculate the annual return on investment of the tank box, the opportunity return to establish the penalty function, the calculation results are shown in the table. Tank container single box annual investment income of 129097.39 RMB, 365 days a year, spread to 353.69 RMB per day. Therefore, at the end consumption point of the tank container single box storage cost of C_w = 354 RMB.

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Table 1. The depreciation of the container

Projects	Value (Unit: RMB)
Price of LNG boxes	640000
Loss rate	5%
Investment years	10
Internal rate of return	15%
Annual return on investment	129097.39

The penalty function established in this paper can be expressed as:

$$F=\begin{cases}365Q\frac{max(t_d)}{t_n}(1/2t_h+t_d-t_n),1/2t_h+t_d+t_a>t_n\\ 0,1/2t_h+t_d+t_a\le t_n\end{cases} \tag{7}$$

Table 2. Transport distance between nodes

Transport arc	Road distance (km)	Rail distance (km)	Sea Distance (n mile)
(s1, t1)	653		
(s1, o1)	817		
(s1, o2)	512		
(s1, t2)	818		
(s2, t1)	433		
(s2, o1)	108		
(s2, o2)	609		
(s2, t2)	128		
(s3, t1)	179		
(s3, o1)	249		
(s3, o2)	101		
(s3, t2)	504		
(o1, m1)			165
(o1, m2)			695
(o1, d1)			112
(o1, d2)			526
(o2, m3)			295
(o2, m4)			283
(o2, d1)			461
(o2, d2)			304
(m1, c1)	208		
(m1, m2)			318
(m3, c2)	314		
(m3, m4)			126
(s4, m3)	98		
(m2, t4)	118		
(m2, c3)	484		
(m2, d1)			115
(m4, t3)	410		
(m4, d2)			94
(m4, c5)	405		
(t3, t4)		231	
(s6, m4)	199		
(s6, t3)	386		
(t4, t5)		493	
(t5, c3)	353		
(t5, c4)	443		
(d1, c3)	455		
(d1, c4)	173		
(d1, c5)	326		
(d2, c3)	449		
(d2, c4)	424		
(d2, c5)	237		
(t6, c3)	673		
(t6, c4)	235		
(t6, c5)	172		
(t6, t5)	938		
(t2, t3)		188	
(t2, t6)		566	
(t1, t4)		308	
(t1, t5)		158	

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3. Empirical Analysis

Transportation distance is an important basis for calculating transportation cost between two nodes, Table 2 shows the statistics of transportation distance between the above nodes; Table 3 shows the transportation rates of each transportation mode; refer to the table of comprehensive operation rates for railroad general container handling, the table of handling rates in the container yard, the table of port rates and other relevant data to give the transit costs between different transportation modes, see Table 4.

Table 3. Freight rates for each mode of transport

	Road transportation	Rail transportation	Waterway transportation
Transportation costs (RMB/per unit container per km or per unit container per n mile)	13.4	19.6	10.9

Table 4. Transfer costs per unit container between different modes of transport

Transport mode	Road transportation (RMB)	Rail transportation (RMB)	Waterway transportation (RMB)
Road transportation	/	120	220
Rail transportation	120	/	160
Waterway transportation	220	160	/

The tank container single box construction cost of 640,000 RMB (i.e., the value of P), taking into account the model decision period, the purchase cost of the box is spread equally to each day, which is transformed into an asset recovery problem. Tank container use time for 20 years, that is, n = 20. F for the future value, that is, 20 years after the residual value, for 5000 RMB, so the model tank container single box purchase cost to take 65000 RMB /per unit container per year.

The above model and data were programmed with the optimization software CPLEX 12.4 under Intel Core i5-2450M CPU @ 2.50GHz, 3G memory, and Windows 7 operating system environment with the default CPLEX solution configuration, and the results are shown in Table 5.

Table 5. Multimodal transport scheme

Distribution path	Transport mode	Transportation Costs (RMB)	Transit costs (RMB)	Total (RMB)
s1-t1-t5-c4	RD-RL-RD	8470.9	240	8710.9
s1-o1-m2-c3	RD-WT-RD	11634.3	440	12074.3
s2-t2-t6-c5	RD-RL-RD	9612.9	240	9852.9
s2-o2-m4-c5	RD-WT-RD	12272.9	440	12712.9
s3-o2-d1-c3	RD-WT-RD	11493.7	440	11933.7
s3-o2-d2-c5	RD-WT-RD	11372.8	440	11812.8
s4-m3-m4-c5	RD-WT-RD	11828.8	440	12268.8
s5-t4-t5-c3	RD-RL-RD	8273.8	240	8513.8
s6-t3-t6-c4	RD-RL-RD	9399.3	240	9639.3

Note: RD means road transportation. RL means rail transportation. WT means waterway transportation.

Considering the characteristics of LNG tanker transportation, which can be transported flexibly and conveniently in the multimodal transportation network, and the high cost of LNG tanker leasing, the decision of distribution route and quantity is studied to make full use of tankers and effectively supplement the pipeline network. The results of the case solution considering the reasonable allocation of LNG tank resources show that the allocation of LNG tank resources affects the choice of different transportation modes, and the "RD-RL-RD" transportation mode is the most economical

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transportation solution to cope with the variable LNG tank resources, and its transportation cost is 8513.8 RMB.

4. Conclusion

In this paper, because LNG in tank containers is affected by many factors in the supply process and its lossless maintenance duration will change dynamically, an objective function model for minimizing transportation cost is established in combination with the actual situation of high requirements for safe storage and transportation of dangerous goods tank containers and high tank rental costs, and the optimal path planning problem of LNG tank container resource allocation is solved by using CPLEX software. Combined with the example to verify that the safe tank transfer is achieved through the optimization scheme, the model can balance the relationship between supplier benefits and coordinated and optimal allocation of LNG resources, and provide some reference for the development of scheduling plan for LNG tank intermodal transportation.

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