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A Study on Location-Route Optimization Model of Logistics Distribution Center and Its Heuristics Solving Algorithm in Multi-Modal Transport Network

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Abstract. Taking environmental concerns into consideration, a logistics distribution center location-route multi-objective optimization model and its solving algorithm are studied in multi-modal transport network context. The objective functions in the model include total operation cost, delivery time and carbon emission goals. The model's decision variables are product volumes with different transport modes and the constraints concerned with investment budget, limited capacity etc. Aimed at the model structure, a two-stage heuristic solving algorithm for single objective model is put forward and its validity is proved. On the basis of solutions which are searched by the heuristic solving algorithm, an optimal solution is obtained using one of multi-objective evaluation methods. Finally, a large scale multi-modal distribution network example is provided to illustrate feasibility and effectiveness of the model and the algorithm by comparing solving efficiency and results, and it finds a railway-based multi-modal transport network has the most competitive advantage.

Keywords. Multi-modal transport, location-route problem, heuristic algorithm, green logistics

1. Introduction

As an important role in logistics and supply chain, transportation not only exerts various impacts on supply chain such as delivery, logistic cost, inventory management etc. [1], but also produces undesirable effects on environment and society, for instance, exhausts emission, noise pollution and traffic safety [2] etc. According to statistics investigation, environmental pollution caused by freight accounts for 14% among the total pollutions, and the percentage of transportation cost in the whole logistics cost is 30-45 [3, 4]. There are multiple transport modes such as road, railway, water and airline, which have their own advantages and disadvantages, and it will face difficulty in meeting requirements, for example, quick response to market, low logistics cost and sustainable supply chain for a single transport mode. Consequently, a reasonable configuration of multiple transport modes, namely multi-modal transport, is becoming a realistic selection for goods distribution.

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Along with the transformation from traditional single transport mode to multi-modal transport mode in modern logistics, researches on multi-modal transport network models and their solving algorithms is gaining more and more attention. Bauer et al (2009) proposed an integer program in the form of a linear cost, multi commodity, capacitated network design formulation that minimizes the amount of greenhouse gas emissions of transportation activities [5]. Anthony Beresford et al (2011) analyzed available multimodal transport route variations for iron ore shipments from northwest Australia to northeast China, focusing on a major iron and steel manufacturer, and the most competitive multimodal transport route, at least in the short to medium term, is found to be a rail-sea-road combination via Port Bayuquan in China [6]. J.H. Cho et al (2012) presented a weighted constrained shortest path problem (WCSPP) model and a dynamic programming algorithm to draw optimal intermodal freight routing with regard to international logistics of container cargo for export and import [7]. Arnab Bhattacharya (2013) developed an approach for intermodal network design based on traffic flow prediction and network optimization via dynamic reallocation/reconfiguration between road and rail networks [8]. Marco Bortolin et al (2016) put forward a three-objective distribution planner to tackle the tactical optimization of fresh food distribution networks considering operating cost, carbon footprint and delivery time goals [9]. Y. Zhao et al (2018) introduced a stochastic intermodal service network design problem in a sea-rail transportation system, which considers stochastic travel time, stochastic transfer time, and stochastic container demand, a hybrid heuristic algorithm incorporating sample average approximation and ant colony optimization is employed to solve this model [10]. Jiehui Jiang et al (2019) investigated a multimodal green logistics network design problem of urban agglomeration with stochastic demand, in which different logistics authorities among the different cities jointly optimize the logistics node configurations and uniform carbon taxes over logistics transport modes to maximize the total social welfare of urban agglomeration and consider logistics users' choice behaviors [11].

In this paper, taking capacity of distribution center as variable, a multi-objective optimization model on location and route of logistics distribution center in multi-modal transport network is introduced and the solving algorithm is designed using a two-stage heuristic algorithm. The main contribution of this work lies in that it will optimize the location selection and transportation route under investment constraint. By introducing a large scale numerical example, the model's feasibility and the solving algorithm' efficiency are validated.

2. Model Proposed

2.1. Problem Description

We study the transportation network model in Figure.1, which shows the logistics distribution network diagram via multi-modal transport. After various goods are produced in supply districts, they're transferred from delivery places to distribution centers, then arriving in receipt places until to their final demand destinations. The problem can be depicted as following: subjected to the total investment, what distribution centers should be selected, what is their capacity, and what kind of transport mode the goods routes should choose so that the total operation costs including production costs, distribution center construction costs and transportation costs) are minimized in minimal delivery time and least emissions during transportation.

For convenience of modelling, assumptions are given as followed.

- Supply points of goods are delivery places, demand points of goods are goods destinations.
- Goods must be transferred from distribution centers without direct shipment from delivery points to destinations directly and no goods transfers among distribution centers.
- Construction and operation costs of distribution center are monotonically increasing with a linear relationship concerned with the handling capacity, i.e., the more capacity of distribution center, the more costs.
- Economy of scope in the transfer point is embodied owing to efficient collaboration among multiple transport modes, that's to say, transportation cost can be reduced, which may be decided by coefficient of scope economy.

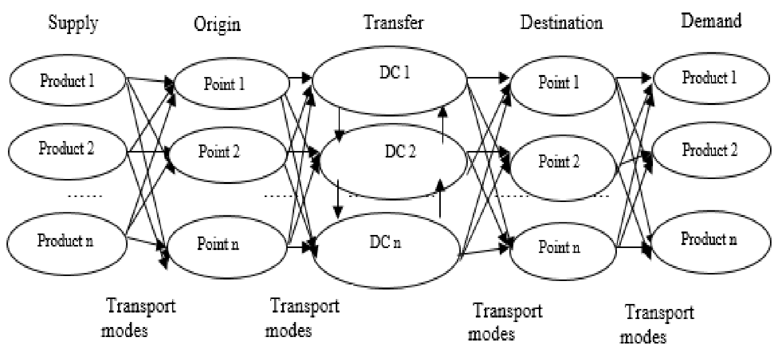

Figure 1. Goods distribution network in multi-modal transport context.

2.2. Model Symbols

The sets, parameters, variables in the model are depicted in Table 1, Table 2.

Table 1. Sets in the model

Sets	Symbol
Products	I, $i \in I$
Origin delivery points	M, $m \in M$
Distribution center transfer points	H, $h \in H$
Destination points	N, $n \in N$
Transport modes	K, $k \in K$
Transportation path	P, $p \in P$
Emissions	E, $e \in E$

Table 2. Parameters, variables in the model

Symbol	Parameter Variable	Description
am_{imp}	parameter	If the origin delivery point of product i in the path m, it's set 1, other 0.
an_{inp}	parameter	If the demand destination point of product i in the path m, it's set 1, other 0
cap_{im}	parameter	The output of product i in supply point m
cs_{ih}	parameter	Unit storage cost of product i in distribution center h
ct_{ip}	parameter	Unit transportation cost of product i in path p
dem_{in}	parameter	Demand quantity of product i in destination point n
d^{k}_{mh}	parameter	Distance between origin point m and distribution center h via transport mode k
d^{k}_{hn}	parameter	Distance between distribution center h and destination n via transport mode k
es^{e}_{ih}	parameter	Unit emission cost of emission e in distribution center h storing product i
et^{e}_{ip}	parameter	Unit emission cost of emission e produced by product i in path p
s_h	parameter	Scope economy coefficient of distribution center h
ts_{ih}	parameter	Storage time of product i in distribution center h
tt_{ip}	parameter	Transportation time of product i in path p
$\alpha^{k}(d^{k})$	parameter	Unit transportation cost function of transport mode k, related with distance
$\beta^{k}(d^{k})$	parameter	Transportation time function of transport mode k, related with distance
$\gamma^{e}_{k}(d^{k})$	parameter	Unit emission function of transport mode k, related with distance
$Inv^{h}(y_h)$	parameter	Construction cost function of distribution center h, related with capacity
B	parameter	Total construction budget of distribution center
ρ	parameter	Weighted coefficient in the distribution center total operation cost
LB_h, UB_h	Parameter	Lower limit, upper limit of distribution center's capacity
x_h	variable	If distribution center h is chosen, 1, else ,0
y_h	variable	Capacity of distribution center h
z_{ip}	variable	Volume of product i via transportation path p from origin delivery point m

2.3. Objectives and Constraints

Three objective functions and constraints in the model are expressed in Eq. (1)-(13).

$$Obj\_Cost = \rho \frac{\sum_{p}\sum_{i} ct_{ip}.z_{ip}}{\sum_{n}\sum_{i} dem_{in}} + \frac{\sum_{h} x_h.Inv^{h}(y_h)}{\sum_{n}\sum_{i} dem_{in}} \tag{1}$$

$$Obj\_Time = \frac{\sum_{p}\sum_{i} tt_{ip}.z_{ip}}{\sum_{n}\sum_{i} dem_{in}} \tag{2}$$

$$Obj\_Emission = \frac{\sum_p \sum_i \sum_e et_{ip}^{e}.z_{ip}}{\sum_n \sum_i dem_{in}} \tag{3}$$

In Eq. (1), total operation cost is computed by adding transportation cost, construction cost of distribution center. Total delivery time is calculated in Eq. (2). Eq. (3) computes total emissions.

$$\sum_p \mathrm{am}_{imp}.z_{ip} \le cap_{im} \qquad \forall i, m \tag{4}$$

$$\sum_p \mathrm{a}\, n_{inp}.z_{ip} \ge dem_{in} \qquad \forall i, \mathrm{n} \tag{5}$$

$$ct_{ip} = \alpha^k (d_{mh}^k) + (1-\mathrm{s})\alpha^k (d_{hn}^k) + c\,\mathrm{s}_{ih} \quad \forall i, p \tag{6}$$

$$tt_{ip} = \beta^k (d_{mh}^k) + \beta^k (d_{hn}^k) + \mathrm{ts}_{ih} \quad \forall i, p \tag{7}$$

$$et_{ip}^{e} = \gamma_k^e (d_{mh}^k) + (1-\mathrm{s})\gamma_k^e (d_{hn}^k) + es_{ih}^{e} \quad \forall i, p, e \tag{8}$$

$$\sum_h x_h.Inv^h(y_h) \le B \tag{9}$$

$$\sum_p \sum_i z_{ip} \le y_h \qquad \forall h \tag{10}$$

$$x_h \in \{0,1\} \qquad \forall h \tag{11}$$

$$LB_h \le y_h \le UB_h \qquad \forall h \quad \mathrm{If}\, x_h = 1 \tag{12}$$

$$z_{ip} \ge 0 \qquad \forall i, p \tag{13}$$

In constraint (4), (5), for a given product, supplier, total volumes of transported products in all paths cant' exceed the product capacity and should meet the product demands. Unit transportation cost, time and emission are calculated in Eq. (6), (7), and (8) for a given product, path, emission. Amount of investment is decided by Eq. (9), which means it is allowed within total budget. Freight handling capacity of a given distribution center is restricted as in Eq. (10). The variables' values are determined by Eq. (11), (12) and (13). The distribution center selection is a binary variable and its capacity is limited to an interval, while volumes transported in a path should be positive.

3. Two-stage Heuristic Algorithm for the Model

3.1. Two-stage Heuristic Algorithm

A two-stage heuristic algorithm is developed to solve the proposed model. On one hand, this multi-objective optimization model can firstly be solved to minimize one of objective functions, so as to get a series of optimal solutions. Then, based on these solutions, we choose the best solution according to (14) as our final optimal result.

$$MinG_j$$
$$G_j = \frac{Obj\_Cost_j}{Obj\_Cost^*} \cdot \frac{Obj\_Time_j}{Obj\_Time^*} \cdot \frac{Obj\_Emission_j}{Obj\_Emission^*} \quad (14)$$

In Eq. (14), Obj_Cost_j 、Obj_Time_j 、$Obj\_Emission_j$ is the corresponding objective function values (cost、transportation time、emission) while Obj_Cost^* 、Obj_Time^* 、$Obj\_Emission^*$ is the minimal of the solutions.

On the other hand, since this model is considered to be a Location-Route problem which can be usually solved using a two-stage algorithm, i.e. firstly to solve location problem, then to search transportation routes. We use a two-stage heuristic algorithm to quickly solve the proposed model considering constraint (9), (12). The procedure is illustrated in the next section.

3.2. Flowchart of Two-stage Heuristic Algorithm

For the sake of clarify this two-stage heuristic algorithm, we define three problems P0, P1, P2 according to the objective functions and constraints. P0 is composed of (1)-(13). Equations (1)-(10), (12), (13) define P1 which means x_h value is determined. P2 is composed of (1)-(8), (10), (12), (13), in which the objective function is in the second part of (1). The two-stage heuristic algorithm's procedure is described as Figure 2.

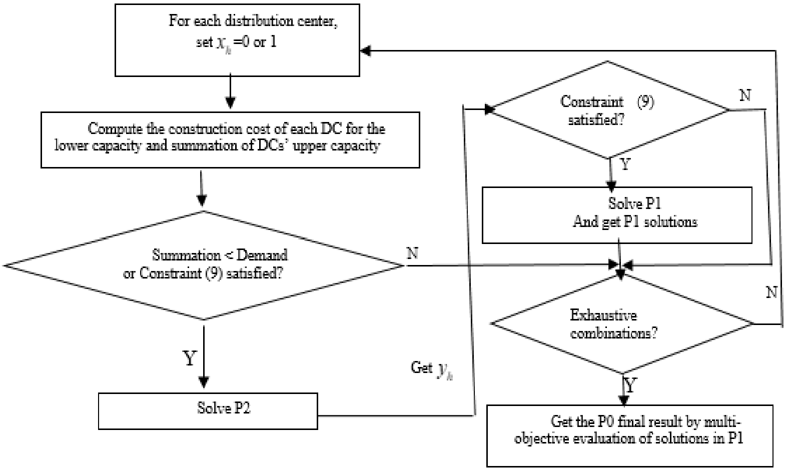

Figure 2. Flow chart of two-stage heuristic algorithm

4. Numerical Example Illustration

4.1. Parameters in Numerical Example

To confirm the proposed model and algorithm's feasibility and effectiveness, on the basis of model and data in [9], a multi-modal transport network is designed which includes 6 products, 18 origin delivery and destination points, 8 distribution centers, 3 transport modes. Different from in [9], only three transport modes (road, rail, airline) are incorporated among origins and distribution centers and destinations. Construction cost function of distribution is listed as below: $Inv^h(y_h) = C_0^h + (y_h - LB_n)C_1^h$ ·

Parameters C_0^h, C_1^h , distances, supplier capacity and customer demands are produced using random functions.

There are 23328 paths in total, 139984 decision variables and 140281 constraints. Cost, time and emission of three transport modes are given in Table 3. Other parameters in the model are set as following: unit storage cost is 2.641, unit emission is 0.6826, storage time in distribution center is 12, scope economy coefficient is 0.25, total budget is 8600000, is 10, and the lower, upper capacity limit is 500, 8000.

Table 3. Transportation cost, time and emission for different transport mods

Transport mode parameter function	**road**	**rail**	**airline**
Unit transportation cost	$0.2782d^{0.817}$	$0.8705d^{0.627}$	$869.32d^{0.139}$
Transportation time	$0.0067d^{1.1465} + 2.823$	$10^{-10} \times d^3 - 10^{-5} \times d^2 + 0.0829 \times d + 22.914$	$0.0023d + 19.254$
Unit emission	$0.484d$	$0.0392d$	$1.67d$

4.2. Results Comparison Analysis

Based on the algorithm above designed and parameters in the previous section, the proposed multi-objective optimization model is solved in the context of CPlex solver, GAMS 24.2, RAM 4G, and CPU 1.4G. To illustrate the feasibility and effectiveness, we compare the efficiency of two-stage heuristic algorithm in Table 4 by relaxing two criterions. The first criterion is: total investment of distribution center selected with lower capacity is less than total budget or sum of upper capacity of distribution center selected is more than products demand in destination points. The second criterion is: construction cost of distribution center which is got by solving P2 is less than total budget.

Table 4. Solving efficiency based on heuristic algorithm

Criterion 1	**Criterion 2**	**Solving time**
No	No	>120 hours
No	Yes	>60 hours
Yes	No	>20 hours
Yes	Yes	<1 hours

From Table 4, it can be seen that computation efficiency is improved a lot by introducing two criterions. Actually, the execute time is about half an hour. The final evaluation results are illustrated in Table 5 which is got by evaluating 56 feasible solutions based on formula (14) (not listed here in a detailed description as space is limited).

As can be seen in Table 5, 13^{th} solution is the best one, which suggests that distribution 1,3,4,5 should be selected, and their capacity is 8000, 8000, 4035 and 6528 respectively. Compared to the maximal cost, time and emission, the percentage of cost reduction, time saving is 6.45, 8.43, while the percentage of cost, time increase and emission reduction is 1.66, 41.27, 41.42 respectively. This means this optimal solution makes a better compromise among three objectives. Also, it finds there are about 92% solutions including railway transport have been suggested which implies that railway maybe an indispensable role in multi-modal transport network.

Table 5. Evaluation of multi-objective optimization solutions

Solution	Index Value	Solution	Index Value	Solution	Index Value	Solution	Index Value
1	1.5415	15	1.6059	29	1.7862	43	1.6920
2	1.5846	16	1.6714	30	1.7494	44	1.6700
3	1.5816	17	1.5786	31	1.7494	45	1.6092
4	1.6897	18	1.6553	32	1.7761	46	1.8349
5	1.6005	19	1.6786	33	1.6883	47	1.9377
6	1.6213	20	1.5982	34	1.6049	48	1.7146
7	1.7395	21	1.6739	35	1.6816	49	1.8890
8	1.6550	22	1.7629	36	1.7468	50	1.8956
9	1.7499	23	1.5917	37	1.7583	51	1.8401
10	1.7128	24	1.7444	38	1.7118	52	1.8596
11	1.7343	25	1.7761	39	1.8021	53	2.0912
12	1.7263	26	1.6801	40	1.8592	54	2.0880
13	1.4361	27	1.8099	41	1.7160	55	1.9473
14	1.4702	28	1.9001	42	1.8646	56	1.9241

5. Conclusion

With rapid development of social economy, logistic distribution is playing a more and more important role in linking production and consumption. Transportation is considered to be a critical activity in logistics and have various positive and negative influences such as delivery, exhaust emission etc. In this paper, we propose an extended multi-objective optimization model on logistics location and route in multi-modal context which is to minimize total operation cost, transportation time and emission. Then, a two-stage heuristic algorithm is designed according to the model's structure. Finally, a large scale numerical example is introduced to illustrate the model's feasibility and the algorithm's effectiveness, also it finds railway can play a critical part in multi-modal transport network. Future studies can be improved by introducing new elements such as inverse logistics or designing more effective algorithms.

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