Available online at www.sciencedirect.com
ScienceDirect
Procedia - Social and Behavioral Sciences 96 (2013) 351 – 359
Procedia
Social and Behavioral Sciences

13th COTA International Conference of Transportation Professionals (CICTP 2013)

The model of location for single allocation multimodal hub under capacity constraints

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Abstract

In a multimodal hub network, the limited resources at the hub may cause shipment delays which will affect the service performance. In this research, hub operations is modelled as a GI/G/1 queuing network and integrates the hub operation queuing model and the hub location-allocation model, then a multimodal hub-and-spoke hub location model considering capacity limit is proposed and tested. The results show that the model can be used to solve the location - allocation problem in the design of multimodal hub network.

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Selection and peer-review under responsibility of Chinese Overseas Transportation Association (COTA).

Keywords: multimodal; hub-and-spoke network; hub location; GI/G/1 queuing system

1. Introduction

Multimodal transportation refers to the integrated use of two or more modes of transportation for delivering goods from origin to destination in a seamless flow [1] [2], which has become the subject and link of modern logistics network operation. Through the multimodal transportation can combine with diverse modes of transport effectively in accordance with the scientific and reasonable process, which can reduce the storage and transit time and customers can get the best transportation route, the shortest transportation time, the highest transport efficiency and the lowest transportation cost consequently. But due to the randomness of the shipping order and interference of time factor, multimodal transportation also has the following insufficient: shipment delay is common due to short of time satisfiability; lack of emergency time strain capacity due to designated transport plan workload is plenty and transport cycle is long; optimization performance is not best so that can't make full use of resources and capacity, etc.

Hub-and-spoke transport scheme can solve some drawbacks of multimodal transport effectively. Hub-and-spoke transportation network is a network (a chart consisted of nodes and connection lines between nodes) which connects most of the nodes and one or more centre hub node and then interaction (see Fig 1), in order to achieve

Subject sources: The central university basic scientific research projects
Project numbers: CHD2011TD015

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Selection and peer-review under responsibility of Chinese Overseas Transportation Association (COTA).
doi:10.1016/j.sbspro.2013.08.042

the network structure which can make an integration of logistics resources and improve utilization efficiency of the logistics resource and reduce logistics cost effectively.

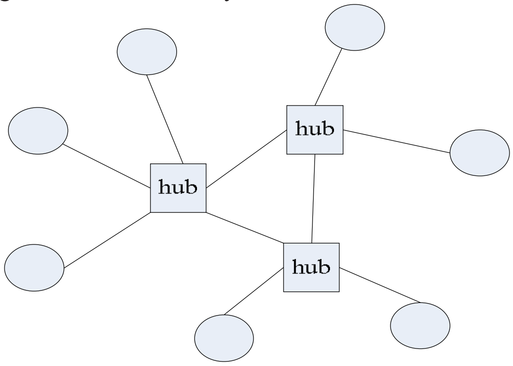


Fig.1. hub-and-spoke network schematic diagram

In a typical hub-and-spoke cargo distribution network, node firstly collects the cargos which are serviced by this node, and then shipment to the hub after assembled. In a hub, the cargo with the same destination and initial address are tidied, and redistribution path is decided according to the destination. If a shipment arrived at a hub and the destination hub link with the hub, it can direct transportation to the destination, or transport to the hub linked with the destination node, then the next step processing. So, the cargo can be concentrated effectively, and the real load rate can be improved, and then achieve economies of scale.

Due to the competitive environment in the market, the enterprise paid more and more attention to the cost and level of service, etc. The mode of multimodal is used widely because it can meet the demand, more and more domestic and foreign scholars begin to study the multimodal transportation, in which the study of multimodal transportation network design and hub location allocation problem is most widely. Arnold [3] et al. presented formulations in which a fixed number of multimodal hubs are selected among candidate locations in 2001, but they only considered the fixed cost of a single hub, ignoring the cost of shipping and storage, and they presented alternate formulations by representing each constituent network as a graph with nodes and arc in 2004, the problem is solved using a heuristic approach involving the solution of a shortest path problem for each commodity (origin-destination pair). Groothedde [4] discussed the implementation of hub-based distribution networks in the consumer goods market in 2005. A road-barge multimodal is compared with the road-only network. A heuristic solution is developed which starts with two hubs and iteratively selects a hub based on improvement in the objective function value, however, there is no specific service time requirements were used in the location/allocation decisions. Wei Zhong [5] et al. studied the model of shortest time and path with the cost of transportation for multimodal in 2006, the paper pays attention to the optimization of path of transportation instead of the selection of hub nodes. Limbourg [6] et al. discussed the location of hubs in a road-rail network. Their solution approach is based on a heuristic which solves the hub location problem completely over road the network first in 2009, but lacks the use of fixed cost and service time restrictions. Yang Youhui[7] studied the location of cargo hubs based on multimodal in 2011. He discussed the influence factors of location for multimodal cargo hubs and evaluation method of the location scheme chiefly. Rafaq Ishfaq and Charles R.Sox [8] studied the design of multimodal logistic networks with hub delays in 2012, but they paid more attention to the analysis of operation procedure of multimodal hubs, and they presented the problem of multimodal transport design, not yet considered the restriction of hub capacity.

The design of multimodal logistics network is more complicated than the design of a single transport logistics network. From the perspective of network design, hub location and allocation problem is integrated into the multimodal logistics network in this research and a multimodal logistics model considering capacity limit is proposed and tested in this paper.

2. Multimodal hub network

In a multimodal hub network， the node represents the city and the arc represents the different modes of transport among cities such as road, rail and airport (see Fig 2). Goods can be transported by any available arc between the two city nodes.

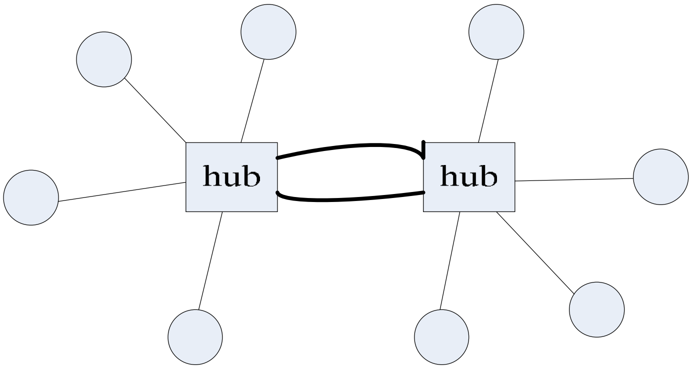


Fig.2. Multimodal hub-and-spoke network

In a multimodal logistics network, the transportation between origin hub k and destination hub m is a kind of transportation with great quality and transport long distance. The goods of city i can be transported to city j by three methods: (1) through direct transportation from city i to city j (see Fig.3. (a)). (2) through single hub from city i to city j which includes two stages, namely, the first stage is the transport from city i to hub k and the second stage is the transport from hub k to city j (see Fig.3.(b)).(3) through a pair of hubs from city i to city j which includes three stages. The first stage is the collection of goods in city i transporting to hub k , the second stage is the transportation between hub k and hub m , the last stage is the process of bulk-cargo from hub m to destination city j (see Fig.3.(c)).

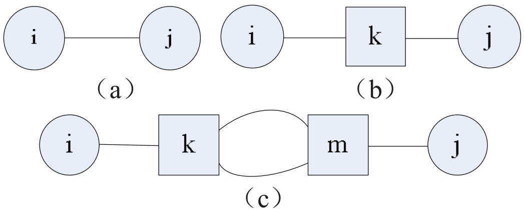
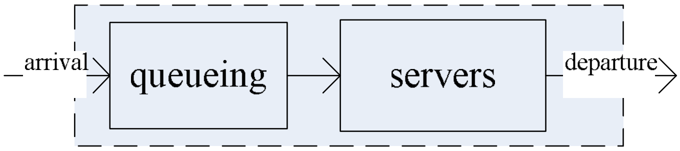


Fig.3 the methods of transportation

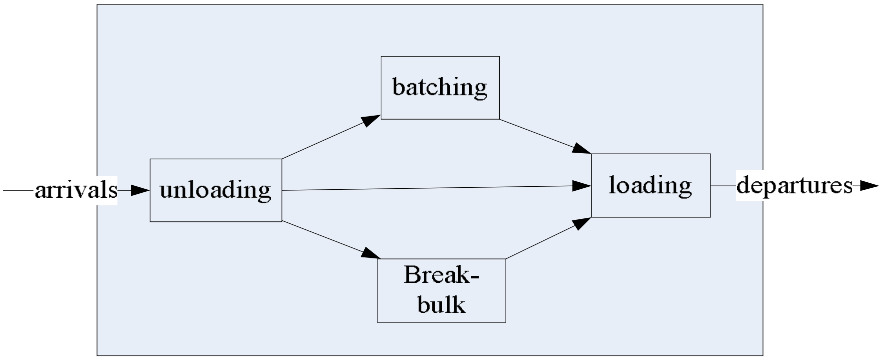
The specific arc chosen in the multimodal hub transportation is given by decision variable X^t_{ijkm} , t represents the method of transport, $t = 1$ means road and $t = 2$ means rail. Additionally, $X^1_{ijkm} = 1$ indicates that the goods of origin-destination (i, j) are transported by road through the pair of hubs (k, m) and $X^1_{ijkm} = 2$ indicates that the goods of origin-destination (i, j) are transported by rail through the pair of hubs (k, m).

3. The queuing system of multimodal hub operations

The hub operations simulate a kind of queue system which is given in Fig.4.



(a) Queuing system of hub



（b）Operational process

Fig.4 Hub queue network and its operational process

In a hub, four different types of operations are undertaken (see Fig.4.(b)).These operations are: (a) unloading, where truck/containers are unloaded and wait for being processed by the unload resources, (b) batching, where cargoes wait for consolidation, (c) break-bulk, where cargoes are separated, and (d) loading operation, where cargoes are loaded in trucks/containers, and delivered to their destination or destination hub.

The following assumptions are made for the hub operation queue system in this paper:

1. The arrived process at a hub according to a general independent random distribution, the service time according to a general random distribution, in other words, the hub simulation is a GI/G / 1 queue system.

2. Infinite queues. The queues are processed by a first come first serve basis. The rule of FCFS implies that the sequence of job departures is identical to that of the arrivals.

3. The queue rules in a hub is waiting system, i.e. when a shipment arrived, it must wait if the unloading resources are busy.

The total waiting time depends on the cargo classes and the routing. Normally, the routing of a shipment is unloading, batch/break-bulk, loading (see Fig.4. (b)). And it is represented by $R_o = \{unload, batch / break - bulk, load\}$ .The total waiting time of a shipment is a sum of waiting times at different operations, consisting of the waiting time of unloading, consolidation, break-bulk and loading. The waiting time at each operation depends on its processing rate and the flows allocated to hubs.

4. Models

The multimodal hub researched in this paper is a load/unload and transfer facility which is capable to deal with two methods of transport. The modelling framework discussed in this section is in the condition of Road-Rail network. However, the framework is also suitable for other multimodal network such as Road-Air and Road-Ship.

To reduce the computational complexity of this problem, the assumption that the transport method of road is used in the collection of goods between origin and its hub and also used in the bulk-cargo between destination and its hub is built in the following analysis, which fits the practical situation.

A multimodal hub location and allocation model considering the limited capacity is built in this paper through the combination of multimodal hub network and queuing system of hub operations. This model has some improvements based on the research of Rafay Ishfaq[9](2012):

(1)A discount of concentrating goods and bulk-cargo is considered during the transportation between the non-hub note and hub note, which is more practical.

(2)The limited capacity of hub is considered in this paper which also fits reality well.

(3)The multimodal hub network is described by network figure which is more audio-visual and more convenient.

The requirement of service time between city i and city j is represented by TW_{ij} in this model. And the unit transport cost between city i and city j depends on the mode of transport t . The unit cost of road ($t = 1$) is charged by the weight (Ton) of each unit goods. In the transportation of rail, the goods are transported by container if they meet the transportation condition of container. But in the general case, the goods meet the transportation condition of container mostly are the expensive, the fragile and the easy wet. Consequently, in order to improve the universality of this model, truckload is used in the transportation of rail and the unit transport cost c_{ij}^2 is charged by Ton.

4.1. Parameters and variables

Decision variables:

$$X_{ijkm}^t = \begin{cases} 1, & \text{the goods transported from i to j through hubs(k, m) using the method of transport t} \\ 0, & \text{otherwise} \end{cases}$$

$$y_k = \begin{cases} 1, & \text{note k is selected as a hub} \\ 0, & \text{otherwise} \end{cases}$$

Parameters:

F_k : The fixed operational cost to set a hub in note k ;

p : The number of hubs;

α : The discount of transport cost between hubs, $\alpha \in \{0,1\}$;

β : The discount of concentrating goods and bulk-cargo between the non-hub note and hub note; $\beta > 1$;

c_{ij}^t : The unit transport cost between note i and note j by using the method of transport t ;

f_{ij} : The float of goods between note i and note j ;

T_{ij}^t : The transport time between note i and note j by using the method of transport t ;

W_k^o : The queuing time of goods in the operation o of hub k ;

s_k^o ； The total service time of goods in the operation o of hub k；

TW_{ij} ： The requirement of transport time between note i and note j；

Q_k ： The capacity of hub k；

4.2. Description of model

$$\min mize \sum_{k\in N} F_k y_k + \sum_{i,j,k,m\in N} \alpha c_{km}^1 f_{ij} X_{ijkm}^1 + \sum_{i,j,k,m\in N,t\in T\setminus\{1\}} c_{km}^2 f_{ij} X_{ijkm}^2 + \sum_{i,j,k,m\in N} \beta f_{ij}(c_{ik}^1 + c_{mj}^1) X_{ijkm}^2$$

S.t.

$$\sum_{k\in N} y_k = p \quad (1)$$

$$\sum_{k,m\in N,t\in T} X_{ijkm}^t = 1, \forall i,j \in N \quad (2)$$

$$X_{ijkm}^t \le y_k, \forall i,j,k,m \in N, t\in T \quad (3)$$

$$X_{ijkm}^t \le y_m, \forall i,j,k,m \in N, t\in T \quad (4)$$

$$\sum_{k\ne m\in N,t\in T} X_{ijkm}^t [T_{ik}^1 + \sum_{O\in R_O} W_k^O + \sum_{O\in R_O} s_k^O + T_{km}^t + \sum_{O\in Ro} W_m^O + \sum_{O\in Ro} s_m^O + T_{mj}^1] \le TW_{ij}, \forall i,j \in N \quad (5)$$

$$\sum_{k\in N} X_{ijkk}^1 [T_{ik}^1 + \sum_{O\in R_o} W_k^O + \sum_{O\in R_o} s_k^O + T_{kj}^1] \le TW_{ij}, \forall i,j \in N \quad (6)$$

$$\sum_{i,j\in N} \sum_{k\in N} f_{ij} X_{ijkm}^t \le Q_k y_k, \forall m \in N \quad (7)$$

$$y_k, X_{ijkm}^t \in \{0,1\}, \forall i,j,k,m \in N, t\in T \quad (8)$$

In this model, the first part of objective function is the total fixed cost to operate a hub. The location of hub is decided by decision variable y_k . The second part and third part of the objective function represent the transport cost of road and other methods of transport respectively. The last part represents the cost of concentration and transportation from origin to its hub and the cost of transportation and bulk-cargo between destination and its hub.

Constraint (1) requires the number of hubs is p . Constraint (2) guarantees that the transportation between one pair of origin-destination can only be realized by one pair of hubs and one method of transport. Constraint (3) (4) indicates that the transportation assigned only under the condition that the hub is built. Constraint (5) (6) are built to make sure that the transportation time of goods are within the limit of required time. Constraint (7) shows the capacity limit of hub. Constraint (8) indicates that y_k , X_{ijkm}^t are 0-1 variables.

5. Model test

A set of data generated randomly is chosen to test this model. Additionally, a case of 10 cities is studied and the parameters are given in table 1, table 2 and table 3.

Table 1 Value of parameters

N	P	α	β
10	4	0.75	2.0

Table 2 the capacity and fixed cost of hubs

notes / attribute	1	2	3	4	5	6	7	8	9	10
Q_k	1638	1275	1031	1621	1086	1384	1276	1599	1841	1340
F_k	350	270	280	250	300	250	230	360	400	450

Table 3 float/cost (road)/time (road)/cost (rail)/time (rail)/TW

	1	2	3	4	5	6	7	8	9	10
1	0/0/0/00/0	18/30/12/10/18/28	20/29/11/9/16/28	15/31/13/10/19/32	8/35/11/11/16/32	15/31/10/10/15/34	25/20/10/6/15/34	14/6/5/2/7/10	20/4/2/2/3/6	30/2/1/1/2/4
2	15/30/12/10/18/28	0/0/0/0/0/0	12/23/12/7/18/28	9/31/10/10/15/34	7/32/11/10/16/34	39/8/5/2/7/12	28/4/5/1/15/12	36/3/4/1/7/10	22/28/10/9/15/28	6/30/12/10/2/28
3	27/29/11/9/16/28	10/23/12/7/18/28	0/0/0/0/0/0	25/3/5/1/7/12	50/2/5/1/7/12	8/32/11/10/16/34	50/35/10/11/15/34	38/20/11/6/16/32	18/23/13/7/19/32	11/20/12/6/18/32
4	16/31/13/10/19/32	8/31/10/10/15/34	28/3/5/1/7/12	0/0/0/0/0/0	42/3/1/1/2/22	13/3/12/1/18/44	16/30/11/10/16/44	9/31/10/10/15/42	9/31/11/10/16/42	8/32/10/10/15/42
5	8/35/11/11/16/32	7/32/11/10/16/34	48/2/5/1/7/12	40/3/1/1/2/22	0/0/0/0/0/0	12/25/12/8/18/44	6/32/10/10/15/44	7/31/10/9/15/42	7/31/11/10/16/42	16/30/12/8/18/42
6	15/31/10/10/15/34	40/8/5/2/7/12	6/32/11/10/16/34	12/3/11/1/18/44	10/25/12/8/18/44	0/0/0/0/0/0	22/5/4/1/6/22	8/28/11/9/16/20	11/30/10/10/15/40	12/30/10/10/15/40
7	25/20/10/6/15/34	30/4/5/1/7/12	50/35/10/11/15/34	15/30/11/10/16/44	7/32/10/10/15/44	20/5/4/1/6/22	0/0/0/0/0/0	44/23/10/7/15/20	13/30/11/10/16/40	9/30/11/10/16/40
8	14/6/5/2/7/10	38/3/4/1/6/10	40/20/11/6/16/32	8/31/10/10/15/42	8/31/10/9/15/42	7/28/11/9/16/20	45/23/10/7/15/20	0/0/0/0/0/0	25/6/5/2/7/16	35/7/6/2/9/16
9	21/4/2/2/3/6	20/28/10/9/15/	20/23/13/7/19/	8/31/11/10/16/42	8/31/11/10/16/	10/30/10/10/15	11/30/11/10/16/4	26/6/5/2/7/16	0/0/0/0/0/0	35/8/6/2/9/6

		28	32		42	/40	0			
10	34/2/1/1/2/4	5/30/12/10/18/28	10/20/6/18/12/32	7/32/10/10/15/42	15/30/12/8/18/42	11/30/10/10/15/40	10/30/11/10/16/40	36/7/6/2/9/16	29/8/6/2/9/6	0/0/0/0/0/0

To reduce the computational complexity, the sum of waiting time and dealing time during each operation in hub is assumed by giving the value 2.5. Namely, the time of goods staying in the hub is 2.5.

The model is solved on a Pentium 2 computer with 2.70GHz and 2GB RAM using Lingo software with above data and the results is achieved as follows:

Fig.5 the solve status of Lingo

Fig.5 shows that the model is a pure integer linear programming model（PILP）, and it has a global optimal solution(Global Opt) after 450 iterations and the best value of objective function is 20713.8. The total number of variables is 20010. The results show that node 1,3,7 and 8 was elected as the hub.

6. Conclusions

In china, logistics industry is in the stage of developing rapidly. Nowadays, most of the logistics hubs are about the single mode of transportation. However, with the reformation of China's railway system , railway transportation will play an increasingly important role in the future and multimodal transport logistics hub will become the trend of the logistics industry. For the location-allocation problem in the design of single allocation multimodal logistics network, an optimization model under the requirements of service time with the objective to minimize total logistics cost is built in this paper. The model is tested by using Lingo software with data which is generated randomly and the results show that this model can be used to solve the location-allocation problem of multimodal hub network.

The model of multimodal hub-and-spoke hub location studied in this paper is based on the simplest queue system and some reasonable assumptions are made in order to reduce the complexity of computation. Actually, the research can be extended too many aspects. For example, a detailed analysis about waiting time and dealing time in the hub queuing system can be developed. Additionally, the problem with large scale can be solved by using heuristic algorithm and some other forms of multimodal transportation can also be considered such as road-ship, road-air and rail-ship.

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