11

Integrated Intermodal Network Design with Nonlinear Inter-Hub Movement Costs

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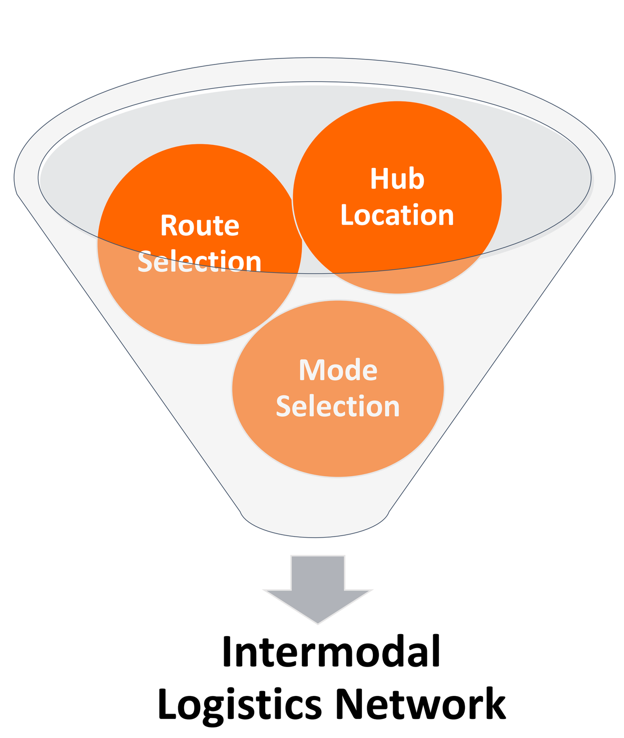
INTRODUCTION

- Intermodal transportation uses at least two different transportation modes to move goods that are in the same transportation unit (i.e., shipping containers) throughout their route from origin to destination (Macharis and Bontekoning 2004).
- Intermodal transportation is an alternative approach that can be used to reduce transportation costs and environmental effects as compared to road transportation.
- One of the key planning decisions associated with intermodal transportation is designing its logistics network.

DIFFERENT ROUTES FOR SENDING A LOAD FROM MINNEAPOLIS TO NEW ORLEANS

INTERMODAL NETWORK DESIGN

Strategic, tactical and operational decisions are involved in designing a logistics network. These decisions are dependent on each other and should be handled together in order to maximize the intermodal transportation system performance.

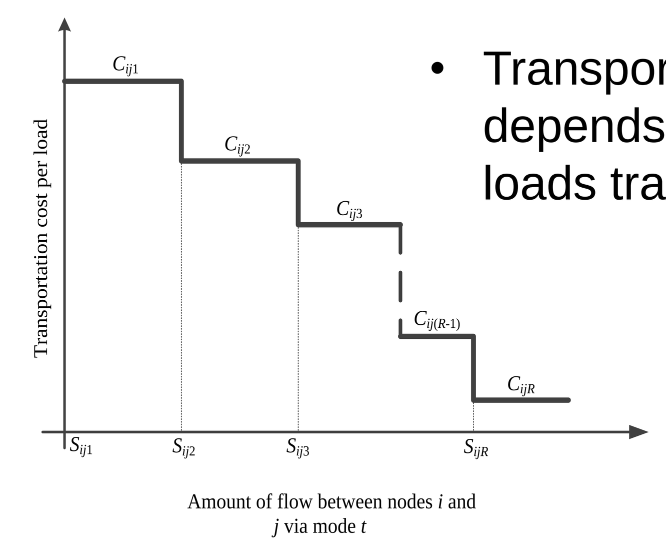


INTEGRATED INTERMODAL NETWORK DESIGN (IILND) PROBLEM

- Designs network topology
- Decisions of different time horizons are integrated in one model
- This model helps the “network operator”

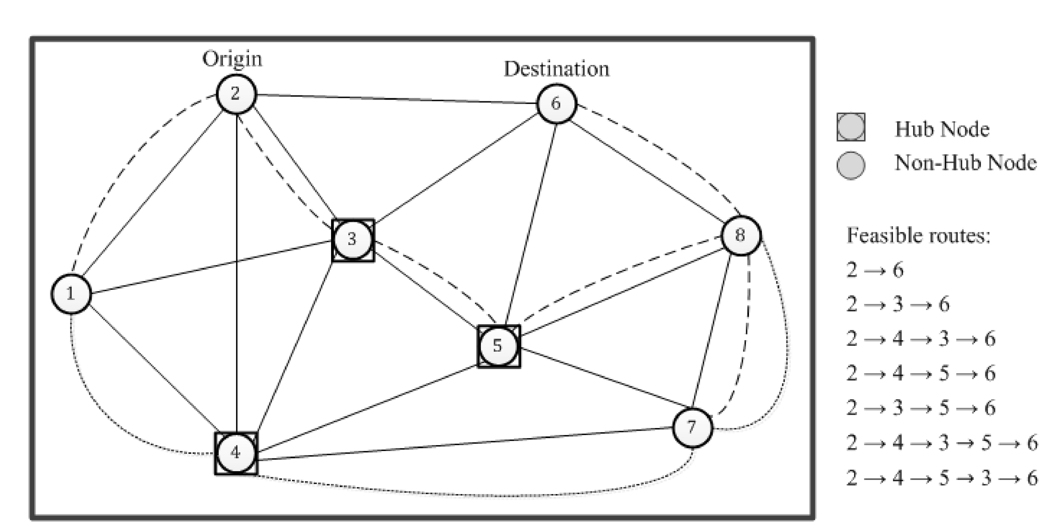
MODELING

- Nonlinear inter-hub movement costs



- Transportation cost per load depends on the amount of loads transported

- Loads are allowed to visit as many hubs as needed to reduce the network total cost



MATHEMATICAL FORMULATION

Decision Variables

$$Y_i = \begin{cases} 1 & \text{if hub } i \text{ is open,} \\ 0 & \text{otherwise,} \end{cases}$$

$$X_{ij}^{p,t} = \begin{cases} 1 & \text{if load } p \text{ is moved from node } i \text{ to node } j \text{ via mode } t, \\ 0 & \text{otherwise,} \end{cases}$$

$$Z_{ijr}^{p,t} = \begin{cases} 1 & \text{if the amount of load } p \text{ that moves from node } i \text{ to node } j \text{ via mode } t \text{ lays on the } r^{th} \text{ step of transportation cost function,} \\ 0 & \text{otherwise.} \end{cases}$$

$$\text{Minimize} \sum_i F_i Y_i + \sum_p \sum_t \sum_i \sum_j \sum_r C_{ijr}^t d_p Z_{ijr}^{p,t} \quad (1)$$

Subject to:

Network Balance:

$$\sum_t \sum_l X_{li}^{p,t} - \sum_t \sum_j X_{ij}^{p,t} = \begin{cases} -1 & \text{if i is origin of } p \\ +1 & \text{if i is destination of } p \\ 0 & \text{otherwise} \end{cases} \quad \forall p, \forall i \quad (2)$$

Use Open Hubs:

$$\sum_t \sum_j X_{ij}^{p,t} d_p \le MY_i \quad \forall p, \forall i \in N - \{Origin_p\} \quad (3)$$

Number of Hubs:

$$\sum_i Y_i = H \quad (4)$$

Cost Function:

$$S_{ijr}^t - \sum_q X_{ij}^{q,t} d_q < M\left(1 - Z_{ijr}^{p,t}\right) \quad \forall i, \forall j, \forall r, \forall t, \forall p \quad (5)$$

$$\sum_q X_{ij}^{q,t} d_q - S_{ijr}^t \le M\left(1 - Z_{ij(r-1)}^{p,t}\right) \quad \forall i, \forall j, \forall t, \forall p, \forall r = 2, \dots, R \quad (6)$$

$$\sum_{r=1}^{R} Z_{ijr}^{p,t} = X_{ij}^{p,t} \quad \forall i, \forall j, \forall t, \forall p \quad (7)$$

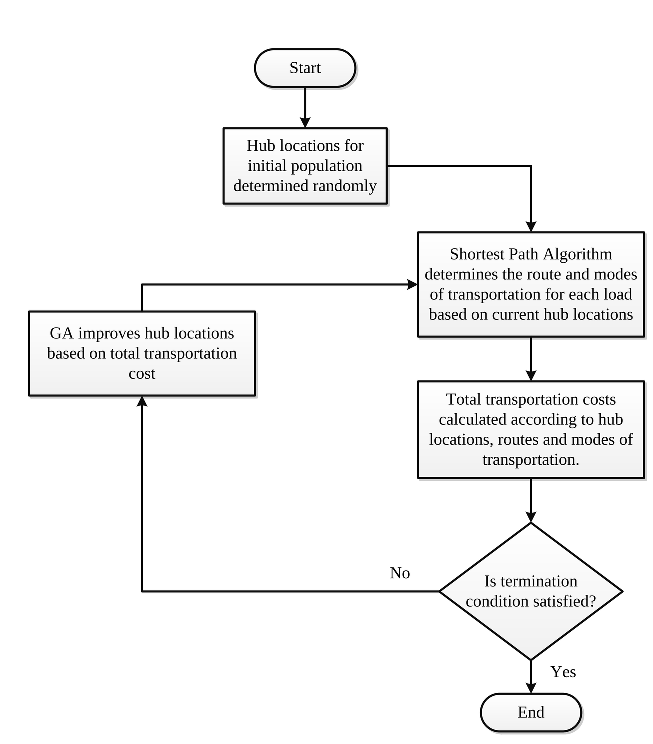
$$Y_i = \{0,1\} \quad \forall i \quad (8)$$

$$X_{ij}^{p,t} = \{0,1\} \quad \forall i, \forall j \quad (9)$$

$$Z_{ijr}^{p,t} = \{0,1\} \quad \forall i, \forall j, \forall r, \forall t, \forall p \quad (10)$$

SOLUTION APPROACH

- A heuristic approach that combines a Genetic Algorithm (GA) and the Shortest Path Algorithm (SPA) was developed

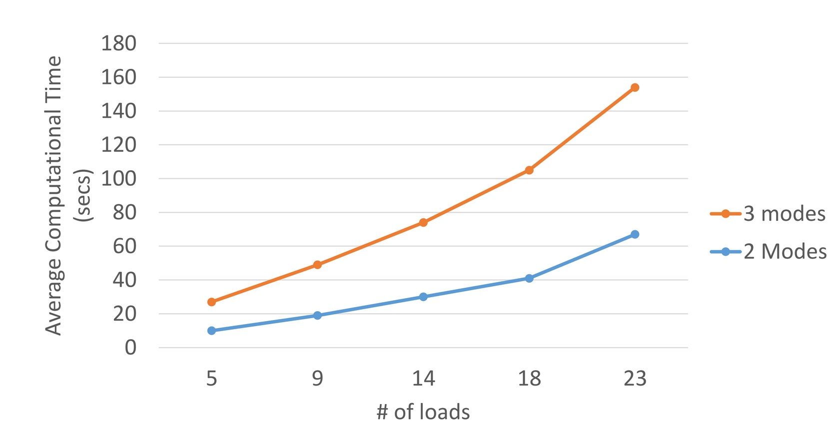


COMPUTATIONAL RESULTS

- Randomly generated instances and the Civil Aeronautics Board (CAB) dataset were used

Heuristic results for random 10-node instances compared to optimal solutions

# of Loads	# of Modes = 2		# of Modes = 3	
	Avg. % Cost Diff.	Avg. % Opt. Hubs	Avg. % Cost Diff.	Avg. % Opt. Hubs
5	0.00	100	0.00	100
9	0.50	100	0.54	100
14	1.00	85	0.60	80
18	3.62	75	1.57	80
23	3.47	70	2.88	50



Heuristic results for total cost and # of hubs for random 25 and 50-node instances

Instance	Measure	N = 25, P = 120		N = 50, P = 490	
		T = 2	T = 3	T = 2	T = 3
1	Cost	4,503.9	3,991.6	13,277.9	12,973.0
	# of Hubs	4	4	5	5
2	Cost	4,792.4	4,390.4	13,987.8	13,023.4
	# of Hubs	5	4	5	4
3	Cost	4,900.1	4,394.4	14,230.4	13,430.0
	# of Hubs	5	3	5	5
4	Cost	4,797.9	4,136.2	14,180.6	12,696.2
	# of Hubs	5	4	5	5
5	Cost	4,862.4	4,367.8	14,183.2	12,755.6
	# of Hubs	5	3	5	5

Heuristic results for CAB dataset (25 nodes) for different fixed cost values

Fixed Cost	T = 2			T = 3		
	Total Cost	% Fixed Cost	# of Hubs	Total Cost	% Fixed Cost	# of Hubs
5,000	135,344	7.39	2	110,275	9.07	2
10,000	145,344	13.76	2	120,275	16.63	2
25,000	162,949	15.34	1	135,359	18.47	1
50,000	187,949	26.60	1	160,359	31.18	1

CONCLUSIONS

- Heuristic method provides optimal solutions for small instances and keeps large proportion of optimal hubs as instance sizes grow
- Large fixed hub installation costs affect number of open hubs
- Additional transportation modes reduce the total transportation cost, however problem size increases and the solution approach requires more time to find solutions (especially for 50-node networks)

FUTURE RESEARCH

- Improving the load route and transportation mode selection portion of the heuristic
- Integrating other related elements that influence the intermodal logistics network design problem such as transportation time and congestion at terminals

REFERENCES

- C. Macharis and Y. Bontekoning, “Opportunities for OR in intermodal freight transport research: a review,” Eur. J. Oper. Res., vol. 153, pp. 400–416, 2004

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