Intermodal network design in freight transportation systems

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***Abstract*—This paper presents a study on intermodal transportation network design problem. The problem is to minimize the total of fixed facility location cost, the transportation cost, the transfer cost, the emission cost, while at the same time, satisfies customer demand, the flow conservation over different transportation mode, the terminal capacity, the vehicle minimum utilization, and the percentage circuitry constraints. The mixed-integer programming model is developed and analyzed with data from the south of Vietnam. The transportation mode of consideration is truck and inland waterway. Results indicate that the intermodal transportation model can reduce the total cost significantly when compared to the unimodal model.**

Keywords— Intermodal transportation, transportation network design, emission cost, intermodal transfer cost.

I. INTRODUCTION

In the recent years, the developing economy and rapidly increasing of weight moving is putting a lot of pressure on the logistics systems. Logistics cost account for approximately 10% in developed countries and 18% in other developing nations. In which, the transportation cost contributes largely for over 50% of the total logistics cost [1]. Transportation is an important activity in logistics systems. It helps connect among regions, hinterland ports with ports, suppliers and customers. The traditional transportation modes include truck, rail, water, and air. Intermodal transportation is an interesting research field which has developed from the late 1980s. Intermodal transportation combines two or many transportation modes to transport commodities or people from its origin to its destination. Developing of intermodal transportation with many modes significantly contributes to the development of trade and the national economy because it helps to save significantly time and cost. Furthermore, intermodal transportation assures that door to door services more effective, reliable, and less interruptions.

II. RELATED WORKS

The choice of transportation mode or combination of modes can impact to efficiency of logistics system and operation costs. Some criteria, such as transportation cost, transfer cost, amount of emission, effective of vehicle capacity, time delivery to select transportation mode. Trucking is usually more expensive than other modes but it has an advantage of door-to-door shipment and a shorter delivery time with no transfer between pickup and delivery. On the other hand, carrying large, heavy, or high density products over long time distances, rail or water transportation is a talent option [2].

For transportation of energy wood, road transportation is the most cost-competitive with distance shorter than 60km and when the distance is longer, rail-road transportation will be a cost-efficient option [3]. Cost of combined transport is 10-20% lower than that of road transport when the distance between the origin and destination is more than 200 km [4]. Wiegmans, et al., (2015) also indicated that an intermodal inland waterway transport is more competitive than a single mode road transport [5]. Not only more cost-effective, another addition of intermodal transportation is that it is environment-friendly. The CO_2 emission in the intermodal transportation is 50% less than the emission of road transportation. The energy efficacy and noise are analyzed by (Kreutzberger, et al., 2003; Craig, et al., 2013) [6], [7].

In a relatively short period of time, there have been many studies relating to the intermodal transportation network, for example, drayage, rail haul, transshipment, road-rail and rail-rail terminals, standardization, multi-castor chain management and control, mode choice and pricing strategies, and intermodal transportation policy and planning [8].

A generic framework for transport network design that considered about the design of transport systems, direct link, corridor, hub-and-spoke, connected hubs, static routes, and dynamic routes is presented and identified by (Woxenius, 2007) [9]. Chang (2008) proposed a model to select the best routes for moving loads through the international intermodal network [10]. Limbourg, et al., (2009) provided an iterative procedure based on both the p-hub median problem and the multi-modal assignment problem to find the number of terminal and the optimal locations [11]. Arnold, et al., (2004) developed a model to select optimal location of rail/road terminals for freight transport network [12]. Van Duin, et al., (1998) gave three-stage modelling for the designing an intermodal transportation services network to select the potential intermodal terminal locations [13].

There are a lot of studies about intermodal transportation network design problem. For different study, the authors concentrate different objective and different constraints such as total cost minimization, transportation cost minimization, emission cost minimization and total transportation times minimization [14] [15] [16] [17]. In this research, the intermodal network design problem presented by (Qu, et al., 2016) is extended, to explicitly include three other factors (capacity utilization of vehicle, detour and capacity in node) affecting the operational performance of the intermodal network [18].

III. Model Formulation

The intermodal logistics network design is studied in a large geographical area, consists of N terminals which are connected by road, railway or inland waterway (Figure 1). Nodes can be the origin or destination of loads or can be transfer points to be linked together by road, railway, airway or waterway.

There are K commodities that are shipped from the origin Ok to the destination D_k with a known demand. Intermodal transportation network design problem can be defined as selecting the routes for loads, and by assigning a number of vehicles to ship commodities from origin to destination. The objective function is to minimize the total network costs, including the fixed, variable, emission, and transfer costs.

The variable costs are charged for shipping on arc A (i, j $\in$ N). The variable costs include fuel costs, crew costs, and other costs on the routes. The transfer costs incur at intermodal node, where commodities are transshipped from one transportation mode to another. The fixed costs consist of establishing transportation links, operating wages, and handling costs from shipping commodities on and off the vehicles. The emission costs are paid for the CO_2 emissions of the vehicles into the atmosphere.

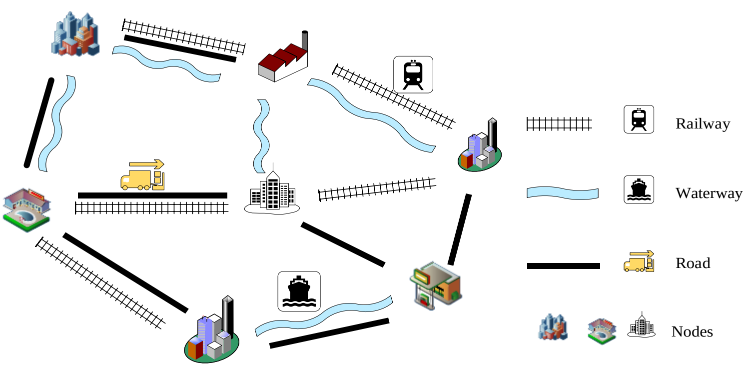

Fig. 1. Intermodal transportation network

A. *Sets and Parameter of model*

N	Set of nodes in the region (1,…, n)
K	Set of commodities (1,…, k)
M	Set of transportation modes (1,…, m)
A	Set of arcs (i, j) (i,j $\in$ N)
c_{ij}^m	Unit transportation costs on arc (i, j) $\in$ A by mode m $\in$ M ($ per tonne-km)
f_{ij}^m	Unit fixed costs for transportation on arc (i, j) $\in$ A by mode m $\in$ M ($ per tonne)
ω	Unit transfer costs ($ per tonne)
p^m	Unit emission costs for mode m $\in$ M ($ per tonne)
d_{ij}^m	Distance of arc (i, j) $\in$ A for mode m $\in$ M (km)
b_i^k	The difference between the quantity of commodity k $\in$ K entering and leaving node i $\in$ N (tonne)
h_i^k	The absolute value of b_i^k (tonne)
u_{ij}^m	The vehicle maximum capacity when traveling on arc (i,j) $\in$ A by mode m $\in$ M (tonne)
O^k	The origin of commodity k $\in$ K
D^k	The destination of commodity k $\in$ K
r^k	The quantity of commodity k $\in$ K to be sent from O^k to D^k (tonne)
φ	The minimum utilization of vehicle capacity (percentage)
$S_{O^k D^k}$	The shortest path distance from node O(k) to node D(k) of commodity k $\in$ K (km)
ε^k	The detour factor for commodity k $\in$ K
V_i	The maximum capacity for node i $\in$ N (tonne)

B. *Decision variables*

x_{ij}^{km}	Flow variable for commodity k $\in$ K on arc (i, j) $\in$ A by mode m $\in$ M (tonne)
y_{ij}^m	Number of vehicles transported on arc (i, j) $\in$ A by mode m $\in$ M (unit)
z_i^{km}	Transferred quantity of commodity k $\in$ K by mode m $\in$ M at node i $\in$ N

C. Mathematical model

$$\text{Minimize} \sum_{k\in K}\sum_{(i,j)\in A}\sum_{m\in M} c_{ij}^{m} x_{ij}^{km} d_{ij}^{m} + \sum_{(i,j)\in A}\sum_{m\in M} f_{ij}^{m} y_{ij}^{m} + \sum_{k\in K}\sum_{(i,j)\in A}\sum_{m\in M} d_{ij}^{m} p^{m} x_{ij}^{km} + \frac{1}{2}\omega \sum_{i\in N}\sum_{k\in K}\left(\sum_{m\in M} z_{i}^{km} - h_{i}^{k} \right) \quad (1)$$

Subject to

$$\sum_{j\in N}\sum_{m\in M} x_{ij}^{km} - \sum_{j\in N}\sum_{m\in M} x_{ji}^{km} = b_{i}^{k} \qquad \forall i \in N, \forall k \in K \qquad (2)$$

$$b_{i}^{k} = \begin{cases} r^{k} & i = O(k) \\ -r^{k} & i = D(k) \\ 0 & \text{otherwise} \end{cases} \quad \text{and} \quad h_{i}^{k} = \begin{cases} r^{k} & i = O(k) \ \text{ or } \ i = D(k) \\ 0 & \text{otherwise} \end{cases} \qquad (3)$$

$$\sum_{k\in K} x_{ij}^{km} \le u_{ij}^{m} y_{ij}^{m} \qquad \forall (i,j) \in A, \forall m \in M \qquad (4)$$

$$\sum_{j\in N} x_{ij}^{km} - \sum_{j\in N} x_{ji}^{km} \le z_{i}^{km} \qquad \forall i \in N, \forall k \in K, \forall m \in M \qquad (5)$$

$$\sum_{j\in N} x_{ji}^{km} - \sum_{j\in N} x_{ij}^{km} \le z_{i}^{km} \qquad \forall i \in N, \forall k \in K, \forall m \in M \qquad (6)$$

$$\sum_{k\in K} x_{ij}^{km} \ge \varphi u_{ij}^{m} y_{ij}^{m} \qquad \forall (i,j) \in A, \forall m \in M \qquad (7)$$

$$\sum_{j\in N}\sum_{m\in M}\sum_{k\in K} x_{ij}^{km} + \sum_{j\in N}\sum_{m\in M}\sum_{k\in K} x_{ji}^{km} \le V_{i} \qquad \forall i \in N \qquad (8)$$

$$\frac{\sum_{(i,j)\in A}\sum_{m\in M} d_{ij}^{m} x_{ij}^{km}}{r^{k}} \le \varepsilon^{k} S_{O(k)D(k)} \qquad \forall k \in K \qquad (9)$$

$$x_{ij}^{km} \ge 0 \qquad \forall (i,j) \in A, \forall m \in M, \forall k \in K \qquad (10)$$

$$y_{ij}^{m} \in \{0,1,2...\} \qquad \forall (i,j) \in A, \forall m \in M \qquad (11)$$

$$z_{i}^{km} \ge 0 \qquad \forall i \in N, \forall k \in K, \forall m \in M \qquad (12)$$

The intermodal transportation network design can be modeled by using a linear mix integer programing on as shown by (1) – (12). The objective function (1) is the total costs of variable, fixed, emission and transfer costs. Constraint (2) is the flow conservation constraint for each node and each commodity. Constraint (3) defines the demand at the origin and the destination node; b_i^k to be the same as the quantity originating at node i if node i is the origin of the commodity k and be the negative value of the quantity if node i is the destination of commodity k; h_i^k is the absolute value of b_i^k. Constraint (4) ensures that the capacity of the vehicle is not overused. Constraints (5) and (6) define the transfer quantity (load and unload) of each mode at every node, and for every commodity. Constraint (7) is the minimum vehicle utilization constraint. This constraint forces the utilization of vehicle to be at least φ percent of the full vehicle capacity. Constraint (8) is the terminal facility capacity constraint. It ensures that the total flows do not exceed the node capacity. If the permissible capacity is set to be lower than the maximum level, the buffer capacity can help avoid congestion and promote smooth operation. The detour constraint (9) ensures that the additional distance is within the ε percent of the shortest possible distance (shortest path distance) over the network. Constraints (10) and (12) are non-negativity conditions for flows and transfer quantity. Constraint (11) is the integer condition.

IV. CASE STUDY

A. Input data

South Vietnam freight transport system consists of road and inland waterway. The length of road in South Vietnam is 50,400 km, but the quality of the road network is not good. Although the government has invested to improve the capacity and quality of the roadway system, the cost of transportation by roadway increased remarkably due to delays in delivery schedules. While there is good potential for waterway transport with more than 3,100 km inland waterway. Most of main rivers, tributaries and canals in the Vietnam flow through most industrial parks, residential areas, and agricultural sector, creating an interconnection, and excellent communication. Inland waterway is a prominent mode of transportation, capable of transport large quantities of goods, the lowest cost, safest and has less environmental pollutions. Besides, inland waterway helps reduce the pressure on transport freight by road. Therefore, the model is developed and analyzed with data from transportation systems in the South Vietnam. The transportation modes under consideration are truck and ship.

Fig. 2. The South Vietnam transportation network

The network consists of 15 nodes, which are provinces in the South Vietnam. They are linked together by road and inland waterway (Figure 2). Every day, commodities is transported from a province to another in the region. In this research, assume that there are 30 different commodities which are moved on the origin-destination pair (Table 1). The distance of origin-destination pair is obtained from the report of World Bank [19], information of 45 main inland waterways routes (http://viwa.gov.vn), inland waterways routes information in South Vietnam (http://cangvudtndhcm.gov.vn). The shortest path for origin-destination pair is calculated by using Dijkstra's algorithm. The road infrastructure in the South of Vietnam allows many types of truck to travel, however the capacity cannot exceed 20 tons [19]. On the river route, maximum capacity of ship is estimated at 1,000 tons [19]. According to RoRo Shipping Company, it is recommended to utilize at least 50-60% of the vessel capacity. Therefore, the minimum utilization of vehicle capacity is 50% in this study.

TABLE I. DEMAND FOR COMMODITIES

Commodity	Origin node	Destination node	Required demand (ton)
1	10	3	1,438
2	1	8	1,340
3	4	5	140
4	5	10	559
5	13	11	1,235
6	6	2	273
7	0	6	507
8	3	10	2,769
9	4	13	135
10	9	3	2,041
11	12	14	116
12	14	4	354
13	3	12	1,381
14	8	12	265
15	2	7	98
16	4	1	2,017
17	1	0	118
18	9	11	164
19	5	4	354
20	11	1	272
21	8	6	1,292
22	9	3	734
23	11	13	489
24	14	7	40
25	8	1	98
26	4	2	114
27	3	11	1,628
28	2	11	742
29	0	9	212
30	5	1	457

The costs in this study consist of the variable, transfer, fixed, and emission cost. The unit variable cost is found from [19], [20]. The unit transfer cost is the unit loading/unloading cost in terminals. Based on the data from inland waterway officers and transportation company, the unit loading/unloading is $2 per ton [19]. Fixed cost of vehicle comprises cost per ton for loading/unloading and the operating wage costs. The unit operating wage cost is reported in "Circular No. 261/2016/TT-BTC" of Ministry of Finance (include maritime fees and charges). Vietnam's government ratified Paris Agreement that has the carbon mitigation goals in dealing with climate change. To achieve commitments of the agreement, many countries applied emission trading system and carbon taxes. According to Economic and Social Commission for Asia and the Pacific, \$10/ton CO_2 emission is reasonable for carbon taxes in the area. In addition, the amount of CO_2 emissions, which arise from truck and ship in transport are presented in [19].

Terminal capacity is defined on the loading/unloading capacity in port that affected the quantity of transferring commodities from one place to an another by inland waterway. The capacity of inland waterway port system in the South of Vietnam is planned in "Decision No: 1108/QĐ-BGTVT" of Ministry of Transport. Table 2 presents the terminal capacity. On the other hand, detour factor is to control the delivery time of commodities. In this study, assume that, the first 5 commodities are fresh food that is required to moved quickly to customer, so the roadway is chosen to transport. Different commodities allow take a detour constraint that it is limit the additional distance to ensure requested delivery time.

TABLE II. TERMINAL CAPACITY

Node	Name	Capacity (tonne)
0	Binh Duong	10,000
1	Dong Nai	15,000
2	Vung Tau	20,000
3	Ho Chi Minh	24,000
4	Long An	19,000
5	Tien Giang	3,000
6	Ben Tre	2,000
7	Tra Vinh	1,500
8	Vinh Long	3,500
9	Dong Thap	2,000
10	An Giang/ Kien Giang	5,000
11	Can Tho	6,000
12	Hau Giang	2,000
13	Soc Trang	4,000
14	Bac Lieu/ Ca Mau	1,000

B. Computational Experiment

The computational experiment is implemented with branch-and-cut approach by using C++ with Concert Technology and CPLEX. The result of experiment is presented in the Table 3. Then the result of intermodal transportation is compared to the result of roadway to evaluate the effectiveness of intermodal transportation network design model (Table 4).

TABLE III. RESULTS OF MODEL

Consideration	Result
Minimum detour	1
Maximum detour	2
Average detour	1.39
Minimum truck utilization	0.5
Maximum truck utilization	1
Average truck utilization	0.93
Number of truck (unit)	426
Total flows by truck (tone)	8,411

Consideration	Result
Minimum detour	1
Minimum ship utilization	0.5
Maximum ship utilization	1
Average truck utilization	0.77
Number of ship (unit)	19
Total flows by ship (tone)	15,677

In Table 3, we can see the detour for commodities range from 1 to 2 with an average 1.39. The minimum and maximum utilization of both truck and ship are 50% and 100% 1. However, the average value of utilization of ship is 77% that is less than value of truck utilization (93%). The number of truck is used to transport more than ship but the total amount of commodity by truck only is 54% compared to the total amount by ship.

TABLE IV. COMPARING THE RESULT OF THE UNIMODAL AND INTERMODAL TRANSPORTATION

Cost	Roadway	Intermodal transportation
Variable cost ($)	302,760	159,894
Fixed cost ($)	183,090	137,020
Emission cost ($)	1,712	1,642
Transfer cost ($)	0	4,010
Total cost($)	487,562	302,566

From Table 4, the variable cost for roadway and intermodal transportation are $302,760, and $159,894, responsively. Intermodal transportation is 47% less costly based on the variable cost than roadway. The variable cost has significant effect on total cost. The fixed cost of intermodal transportation is $137,020, which is 25% less than that of roadway. The emission cost of the roadway is also higher than intermodal because the unit emission cost for truck higher than unit emission for ship. Thus, intermodal transportation has less environmental pollution. The transfer cost is only incurred when the commodity transshipped from one transportation mode to another. The total cost of unimodal transportation is much higher than the cost of intermodal transportation. The total cost of intermodal transportation, which is $302,556, is 38% less than the total cost for road. From the results, the intermodal transportation that combines road and inland waterway is more environmental friendly and less costly than the roadway transportation.

Based on the finding of this research, the government of Vietnam should provide more facilities to support intermodal transportation. Companies and logistics providers should try to use more inland waterway for transportation although it is less convenient since it can reduce total costs significantly and more environmental friendly.

V. CONCLUSION

This research addresses an intermodal transportation network model that consists of the selection transportation modes and routes to ship cargo from origins to destinations. This is done by proposing an optimization model to minimize total cost including fixed cost, transportation cost, emission cost and transfer cost. Besides, the customer satisfaction, effective resources, and profit of carriers are archived by considering the terminal capacity, vehicle minimum utilization, and the percentage circuitry constraints.

This research has some limitations as follows. It considers only two modes of transportation, road and inland waterway. The number of nodes (15) is still small. The related costs are constant without any uncertainty. Further research is recommended as follows. More varieties of transportation modes should be considered. The number of nodes should be increased to represent -sized problems. Uncertain (fuzzy) cost parameters should be considered.

This research has both theorized and practical contributions. Theoretically, it proposed a mixed integer linear programming model which is capable to solve the intermodal transportation system. Practically, it demonstrates that the model can be applied with a real case of intermodal transportation system in South Vietnam with 15 nodes. Results encourage the government to build more infrastructure for intermodal transportation.

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