DESIGNING AN INTERMODAL TRANSPORTATION NETWORK: A CASE STUDY IN VIET NAM

BY

TRAN QUYNH LE

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING (LOGISTICS AND SUPPLY CHAIN SYSTEMS ENGINEERING)

SIRINDHORN INTERNATIONAL INSTITUTE OF TECHNOLOGY

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A Thesis Presented

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Abstract

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TRAN QUYNH LE

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The ITND model developed in this study addresses the construction of the intermodal transportation network and finding the transportation routes for each commodity from the origin to destination. The objective function was to minimize the total cost, including the fixed transportation cost, the variable transportation cost, the emission cost, and the transfer cost. The model also included the node capacity constraints, the detour constraints, and the vehicle utilization constraints. The model was tested with data from the south of Viet Nam transportation network. Multiple experiments were conducted in order to observe the effect of each constraint and the characteristics of the model with different constraint set. The results show that by including all constraints to the model, the resulting network perform better in terms of terminal capacity (and traffic), additional transportation distance (detour), and vehicle utilization, with the expense of increasing the total cost by 20%. In addition, fuzzy factor was incorporated to the model and analyzed in order to better understand the model under uncertainty.

Keywords: Intermodal transportation, transportation network design, traffic congestion, vehicle capacity utilization, detour factor, transportation costs.

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Chapter 1

Introduction

1.1 Problem statement

The globalization, the advancement in technology, and the overly increasing population have significantly accelerated the change in international trade and economy. The competition is very intense like never before, and the efficiency of the logistics management has now become a key factor affecting the economic development. One of the key performance indicators is the transportation cost that contributes largely for over 50% of the total logistics cost (Bardi, E. J., et al., 2006); this makes it one of the major concerns of the industry. In order to reduce such expense, the transportation has to operate as optimal as possible and require a good transportation system to operate. Specifically, the efficient transportation system allows the transportation to possibly be cheaper, faster, safer, more reliable, and less interruptions. However, achieving this goal is very difficult, especially, when multiple transportation modes co-operating on the same system are considered.

Different transportation modes are different in terms of service price, speed, reliability, accuracy, scheduling, convenience, and safety (Punakivi, M., et al., 2006). The detailed study for comparing different transportation modes with the effects of distance, shipping time, fuel cost, weight and value of commodity can be found in (Chopra, S., et al., 2013). Among all modes, trucking is usually more expensive but it has many other competitive advantages (e.g. door-to-door shipment and short delivery time) (Samimi, A., et al., 2011). Rail and water transportation are usually more efficient for carrying large, heavy, and high-density load over long distances in the expense of much longer transportation time. To this end, the intermodal transportation combines different transportation mode in order to overcome weaknesses and utilize the strength of each mode. Potential benefits of intermodal transportation include the opportunity to

1) achieve efficient operation and economies of scale

2) improve vehicle capacity utilization

3) decrease congestion

4) reduce emissions into the environment

5) create a safety and reliability system.

These benefits are efforts toward the ultimate goal to improve service quality and reduce the cost.

The cooperation in intermodal transportation requires shipments to transfer from one mode to another at intermodal terminals (Crainic, T.G., et al., 2007). The transfer at these terminals, and the movement (of all transportation modes) between terminals can define the performance of the whole system. Therefore, the intermodal transportation network must be pre-determined for the intermodal transportation to operate. The network must allow a synchronized movement and transfer, in order to achieve a good transportation system, which will eventually allow the transportation to possibly be more efficient.

1.2 Research objective

The objective of this research is to construct an intermodal transportation network and determine the transportation routes for all commodities from origins to destinations over the network in such a way that indicates good logistical performance. Moreover, the objective function consists of the transportation cost, both fixed and variable cost, the transfer cost, and the emission cost.

1.3 Addressed issues

This study 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. The demand of stakeholder in transportation network (port agents, customers and carriers) is satisfied by different constraints. The terminal capacity constraints are added to provide the limitation of traffic at a node. The delivery time is controlled by the detour constraints. The vehicle minimum utilization constraints ensure effective operation of vehicles for carriers. The MIP model is developed and analyzed with data from the south of Vietnam. The transportation modes of consideration are truck and ship.

1.3.1 Terminal capacity and congestion

Traffic congestion usually appears in the terminals, IDCs (inland depot container), or ports, where the commodities are transferred between modes. Traffic congestion is characterized by the sluggish speeds and long queuing that results from the over utilized facility. Limitation of equipment capacity can also create congestion within facilities. Congestion at terminals has significant impact on transportation decisions, especially the terminal location selection and the route selection. Congestion due to too much traffic at the node potentially leads inferior performance and additional cost, both directly and indirectly. This study considers capacity constraint in node to limit the traffic flows and improve the smooth operation so as to provide high quality of service to customers.

1.3.2 Detour factor

In transportation, the transportation routes to move the commodities depend on the characteristic of commodities and delivery time requirement of the customer. Frozen and fresh food must be rapidly transported to consumer markets. Other products might be transported slower in order to save cost. The detour factor controls the additional distance that affects the intermodal transportation network performance. Intermodal transportation network has many terminals where commodities can be transferred from one transportation mode to another. When there is some capacity left in the vehicles, the drivers can travel to another terminal to pick up more commodities; this may increase the travel distance and the transportation time

1.3.3 Capacity utilization of vehicles

Capacity utilization of vehicle is defined by the ratio between the carry amount on the vehicle and the maximum amount that vehicle can carry. Efficient utilization of the vehicles is one major factor that affect carrier's profit. Therefore, the carrier must ensure effective usage of the vehicles and maintain a high vehicle’s utilization.

1.4 Scope and Limitations

Intermodal transportation is an interesting research field which has been developed from the late 1980s. In a relatively short period of time, there have been many studies relating to the intermodal transportation network that are reviewed by Macharis. Drayage, rail haul, transshipment: road-rail terminals and rail-rail terminals, standardization, multi-castor chain management, and control, mode choice and pricing strategies, and intermodal transportation policy and planning are the main works to be discussed (Macharis, C., et al., 2004). This research only focuses on some selected fields which are key components in the development of freight transportation systems in Vietnam and suggests a model that can minimize the total cost.

1.5 Overall of research

This dissertation presents a study on intermodal transportation network design. In this study, the selection of transportation mode and the route to transport commodities from origins to destinations are identified, and based on a series of constraints while minimizing the total cost. Vehicle utilization, terminal capacity and, additional distance constraints are added into the model to ensure efficient operation, on time delivery, and stakeholders' profit. The model will be solved by exact algorithm. Viet Nam transportation system is used as a case study to illustrate on how to apply model to a real world data.

1.6 Organization of research

This thesis is divided into 6 chapters as follow:

Chapter 1: Introduction – this chapter gives an overview and objectives of the research, as well as, the structure and methodology apply for this research.

Chapter 2: Literature review – this chapter focuses on previous research of other authors involving the intermodal transportation in other countries and models to select modes and routes from origins to destinations.

Chapter 3: Problem is defined and the mathematical formulations are presented.

Chapter 4. Vietnam transportation network is considered as a case study that provides a case study.

Chapter 5: This chapter develops a method for solving fuzzy intermodal transportation network design model.

Chapter 6: Conclusion – the summaries of all findings and the suggestions on some possible future research.

Chapter 2

Literature Review

2.1 Intermodal transportation network

The discussions over the benefits of intermodal transportation could be found widely in the literature. The transportation of energy wood over the road was the most cost-competitive only when distance was short (60 km. or less) (Tahvanainen, T., et al., 2011). However, over longer distance, the combination of railway and roadway was more cost-effective. Similar result was reported for the comparison between the intermodal transportation with inland waterway and roadway transportation (Wiegmans, B., et al., 2015). Combining roadway transportation to other modes could lower the transportation cost by around 10-20% of those of road transportation (Fremont, A., et al., 2010), especially when the distance was more than 200 km. Not only in terms of cost reduction, environmental friendliness was also another major benefit of intermodal transportation. In addition to cost reduction, the environmental friendliness was also one of the major concerns. The CO_2 emission was reduced about 50% in the intermodal transportation comparing to truckload transportation as well as the energy efficacy and noise reduction (Kreutzberger, E., et al., 2003; Craig, A. J., et al., 2013).

There are many studies on the design of the intermodal network. Designing an intermodal network includes defining of intermodal terminal location and selecting of appropriate transportation route. It was described and introduced as an alternative direction for saving the operating costs and reducing emissions of transportation in Mostert, M., et al. (2017). Limbourg, S., et al., (2009) provided an iterative procedure to find the optimal locations for a given number of hubs. Arnold, P., et al., (2004) developed a model to select optimal location of rail/road terminals for freight transportation network. Van Duin, R., et al., (1998) presented the three-stage model to find the terminal location and the simulation for the design of intermodal transportation services. Chang, T. S. (2008) proposed a model to select the best transportation routes over the international intermodal network. Mathematical models and solution methodologies for the intermodal transportation network design problem could be found in (Crainic, T. G., 2000; Resat, H. G., et al., 2015; Demir, E., et al., 2016; Ghane-Ezabadi, M., et al., 2016). Moreover, a generic framework for transport network design was presented and identified in Woxenius, J. (2007); the framework considered 1) *the design of transport systems*, 2*) direct link*, 3) *corridor*, 4) *hub-and-spoke*, 5) *connected hubs*, 6) *static routes*, and 7) *dynamic routes*.

In general, the transportation network design problem considered constructing the transportation network while minimizing the total of the facility cost and the transportation cost. The intermodal network problem normally includes the emission cost to the total cost. In this study, the intermodal network design problem presented in Qu, Y., et al., (2016) was extended to explicitly include three other factors, 1) *facility capacity*, 2) *capacity utilization of vehicle*, and 3) *detour limitation*. These factors immensely affected the operational performance of the intermodal network.

2.2 Terminal capacity and congestion

The capacity of terminal facilities and traffic congestion are highly related to each other. Intermodal transfer and sorting/resorting activity (with or without the mode transfer) takes place at the terminal facility. If the terminal capacity is high enough, then the terminal can serve large amount of commodity in reasonable time. On the other hand, if the capacity is relatively low, then congestion is to be expected whenever the facilities are overly utilized. The overuse of terminal facilities and congestion have significantly impacted on the efficacy of the transportation network as a whole.

Capacity constraints were normally found in mathematical model. Rodriguez, V., et al. (2007) proposed the method to find congestion cost in hubs. They also proposed that the balance of flows in hubs can potentially improve travel times and, eventually, improve customer service efficiency. A hub-and-spoke network design model with traffic congestion was also developed in Elhedhli, S., et al. (2005).

2.3 Detour factor

Detour factor that can be defined as the ratio between the length of additional distance from origin to destination and the length of the shortest path for any commodity (Geisberger, R., et al., 2009). This additional distance is normally kept at minimum level due to its effect on the transportation cost, the fuel cost, the driver's cost, and many more. However, it is not always the case that the additional distance can be avoided, and the commodity can be transported directly from the origin to the destination. Especially in the intermodal transportation network design model that commodities change transportation mode, but only at the terminal facilities. Therefore, commodities must take a detour to terminal facility in order to change into a more efficient transportation mode, and achieve economy of scale. Some discussion about detour in transportation network can be found in the literature. Ballou, R. H., et al., (2002) indicated that detour factor depend on network density, the number of terminal in network, and natural obstacles. Jung, J., et al., (2013) presented a heuristic algorithm to maximize the profit with subjected to limited detours. In term of mathematical model, Üster, H., et al., (2007) derived a network design model with a circuitry constraint and developed a heuristics method to solve the model. Üster, H., et al., (2011) extended the model to include load-imbalance constraints and developed a Benders decomposition algorithm to solve the model. In comparison, their percentage circuitry constraint considered unimodal transportation, whereas, the detour constraint herein considered the weight average of multiple transportation modes and routes.

2.4 Capacity utilization of vehicles

Another factor affecting the intermodal transportation network design performance is the utilization of the vehicle. Maximizing vehicle utilization can help saving cost and reducing the delivery time (Sarkar, A., et al., 2008). However, maximizing capacity utilization of vehicles is not only very difficult, but also based on customer demands, characteristic of good, and schedule plan. The detailed studied on the vehicle capacity utilization in freight transportation was introduced and applied in various applications (Abate, M. A., et al., 2013). The utilization of vehicles has been considered in many studies for unimodal transportation. McKinnon, A., et al., (2010) reported that there are many causes that affect the utilization of trucks capacity in transportation (e.g. the market, regulation, inter-function, infrastructure, and equipment). For waterborne transportation, Styhre, L., (2009) examined vessel capacity utilization and analyzed strategies to enhance vessel capacity utilization. Maraš, V., et al., (2013) showed that the average utilization of the barge container of 88% is the level that maximize the profit of a shipping company. Moreover, according to the Liner Service Providers in study (Gelareh, S., et al., 2013), 50%-90% of the vessels capacity was used to ensure profit for company. In modeling aspect, Goetschalckx, M., et al., (1989) established a mathematical model for minimizing the total truck travel distance with respect to truck capacity. K Kim, H., et al., (2009) proposed an efficient vehicle route planning that minimize the trip distance with respect to vehicle capacity utilization constraint.

Chapter 3
The Intermodal Transportation Network Design Model

This chapter develops the model formulation and proposes the mathematical model. Section 3.1 describes the problem definition. Section 3.2 and 3.3 declare the sets, parameters and decision variables. Section 3.4 presents the mathematical formulation, including objective function and constraints

3.1 Problem description

The intermodal transportation network design model (ITND) in this study considers a large geographical area that consists of N nodes. These nodes are terminals (e.g. seaport, inland port, inland container depots, industrial park) that shipments can (but not necessary) change modes. They are connected by either roads, railways, or inland waterways as shown in Figure 3.1. All connections are represented by A_{ij} ($i, j \in N$). Moreover, there are K commodities and some of the nodes are the origin O^k or the destination nodes D^k of a commodity $k \in K$. The objective of the ITND model is to construct an intermodal transportation network by considering the arc A_{ij} to be used in the final network. The network should contain the routes for all commodities, from their origins to destinations so that the transportation is as efficient as possible. Therefore, the objective function composes of the transportation cost, both fixed and variable, the transfer cost, and the emission cost. The variable transportation cost includes the fuel costs, crew costs, and any other cost occur during the transportation. The fixed transportation cost occurs while establishing transportation links, operating wages, and handling commodities (loading/unloading commodities on and off the vehicles). The transportation cost directly associates with the ability of the network whether it allows the carriers to operate efficiently or not. The transfer cost, on the other hand, indicates how often the mode exchanges take place. Mode exchanges allow the carriers to utilize a more economical transportation mode. For the emission cost, it is charged for a release of the greenhouse gas from the vehicles into the atmosphere. Vehicle with economy of scale usually has lower emission cost. Thus, the emission cost indirectly indicates the availability of a more environmental friendly mode to the shippers.

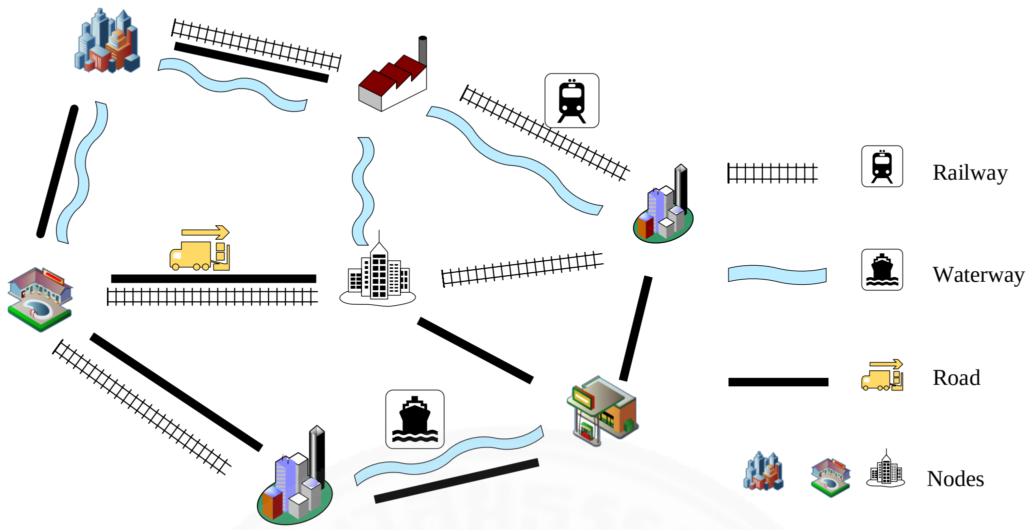

Figure 3.1 Intermodal transportation network

3.2 Set and parameter

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 ton-km)
f_{ij}^{m}	Unit fixed costs for transportation on arc (i, j) $\in$ A by mode m $\in$ M ($ per ton)
ω	Unit transfer costs ($ per ton)
p^{m}	Unit emission costs for mode m $\in$ M ($ per ton-km)
d_{ij}^{m}	Distance of arc (i, j) $\in$ A for mode m $\in$ M (km)
$S_{O^kD^k}$	The shortest path distance from node O^k to node D^k of commodity k $\in$ K (km)
b_{i}^{k}	The difference between the quantity of commodity k $\in$ K entering and leaving node i $\in$ N (ton)
h_{i}^{k}	The absolute value of b_{i}^{k} (ton)

u_{ij}^{m} The vehicle maximum capacity when traveling on arc $(i,j) \in A$ by mode $m \in M$ (ton)

O^k The origin of commodity $k \in K$

D^k The destination of commodity $k \in K$

r^k The quantity of commodity $k \in K$ that is to be sent from O^k to D^k (ton)

φ The minimum utilization of vehicle capacity (%)

ε^k The detour factor for commodity $k \in K$

V_i The maximum capacity for node $i \in N$ (ton

3.3 Decision variables

x_{ij}^{km} Flow variable for commodity $k \in K$ on arc $(i, j) \in A$ by mode $m \in M$ (ton)

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 $i \in N$

3.4 Mathematical modelling

$$\text{Minimize} \quad \sum_{k\in K}\sum_{(i,j)\in A}\sum_{m\in M} c_{ij}^{m} x_{ij}^{km} d_{ij}^{m} + \sum_{(i,j)\in A}\sum_{m\in M} f_{ij}^{m} y_{ij}^{m}$$

$$+\sum_{k\in K}\sum_{(i,j)\in A}\sum_{m\in M} d_{ij}^{m} p^{m} x_{ij}^{km} + \frac{1}{2}\omega\sum_{i\in N}\sum_{k\in K}\left(\sum_{m\in M} z_{i}^{km} - h_{i}^{k}\right) \tag{3.1}$$

subject to

$$\sum_{j\in N}\sum_{m\in M} x_{ij}^{km} - \sum_{j\in N}\sum_{m\in M} x_{ji}^{km} = b_{i}^{k} \qquad \forall i \in N, \forall k \in K \tag{3.2}$$

$$b_{i}^{k} = \begin{cases} r^k & i = O^k \\ -r^k & i = D^k \\ 0 & \text{otherwise} \end{cases} \quad \text{and} \quad h_{i}^{k} = \begin{cases} r^k & i = O^k \text{ or } i = D^k \\ 0 & \text{otherwise} \end{cases} \tag{3.3}$$

$$\sum_{k\in K} x_{ij}^{km} \leq u_{ij}^{m} y_{ij}^{m} \qquad \forall (i,j) \in A, \forall m \in M \tag{3.4}$$

$$\sum_{j\in N} x_{ij}^{km} - \sum_{j\in N} x_{ji}^{km} \leq z_i^{km} \qquad \forall i \in N, \forall k \in K, \forall m \in M \qquad (3.5)$$

$$\sum_{j\in N} x_{ji}^{km} - \sum_{j\in N} x_{ij}^{km} \leq z_i^{km} \qquad \forall i \in N, \forall k \in K, \forall m \in M \qquad (3.6)$$

$$\sum_{j\in N}\sum_{m\in M}\sum_{k\in K} x_{ij}^{km} + \sum_{j\in N}\sum_{m\in M}\sum_{k\in K} x_{ji}^{km} \leq V_i \qquad \forall i \in N \qquad (3.7)$$

$$\frac{\sum_{(i,j)\in A}\sum_{m\in M} d_{ij}^{m} x_{ij}^{km}}{r^k} \leq \varepsilon^k S_{O^k D^k} \qquad \forall k \in K \qquad (3.8)$$

$$\sum_{k\in K} x_{ij}^{km} \geq \varphi u_{ij}^{m} y_{ij}^{m} \qquad \forall (i,j) \in A, \forall m \in M \qquad (3.9)$$

$$x_{ij}^{km} \geq 0 \qquad \forall (i,j) \in A, \forall m \in M, \forall k \in K \qquad (3.10)$$

$$y_{ij}^{m} \in \{0,1,2...\} \qquad \forall (i,j) \in A, \forall m \in M \qquad (3.11)$$

$$z_i^{km} \geq 0 \qquad \forall i \in N, \forall k \in K, \forall m \in M \qquad (3.12)$$

The ITND can be modeled by using a linear mix integer programing formulation as (3.1) – (3.12). The objective function (3.1) is the total cost from the transportation cost, the fixed cost, the emission cost, and the transfer cost. Constraints (3.2) are the flow conservation constraints for each node and each commodity. Constraints (3.3) define to be equal to the demand whether or not the location is the origin or the destination of a commodity. Constraints (3.4) ensure that the capacity of the vehicle is not overused. Constraints (3.5) and (3.6) define the transfer quantity (loading and unloading) of each mode at every node, and for every commodity. Constraints (3.7) are the terminal facility capacity constraints. They ensure that the total flows do not exceed the node capacity. If the permissible capacity is set to be lower than the maximum level, the remaining capacity acts as a buffer to help avoid congestion and promote smooth operation. Constraints (3.8) is the detour constrains. The left hand side defines the weight average network distance of a commodity, whereas the right hand side is permissible additional distance for each commodity. The detour constraints (3.8) ensure that the additional distance is within ε percent of the shortest possible distance (shortest path distance) over the network. Constraints (3.9) is the minimum vehicle utilization constraints. These constraints force the utilization of vehicle to be at least φ percent of the full vehicle capacity. Constraints (3.10) and (3.12) are non-negativity constraints for flows and transferred quantity. Constraint (3.11) is the integer requirements for the number of variables.

Chapter 4
Computational Experiments

This chapter presents the computation experiments using the case study that base on the intermodal transportation network that combines road and inland waterway in the South of Viet Nam. In order to develop the mathematical model of the case study, some input data must be prepared in advance. The preparation and all analysis are presented in section 4.1, 4.2, 4.3, 4.4, 4.5, and 4.6; these sections include the information of the transportation network, vehicle capacity, demand of commodities, terminal capacity, detour factor, and setting up experiment. Section 4.7 provides the result and analysis of solving the mathematical model with the data.

4.1 Description of input data

The intermodal model was tested with data from the South of Viet Nam's transportation network that consisted mainly of inland waterway and road. The network consisted of 15 nodes, which represented the major provinces in the South of Viet Nam. These provinces are randomly assigned to be the origin or the destination of 30 different important commodities to be transported forward and backward between the origins and destinations (Table 4.1). The volume of the commodity to be transported was estimated following the study of World Bank (Blancas, L. C., et al., 2013). All 15 provinces are linked together either by road and/or inland waterway, as shown in Figure 4.1.

The transportation network data used in this research was gathered from many sources especially for the distance ($i, j \in N$). For the road network, the distance data was obtained from the report of the World Bank (Blancas, L. C., et al., 2013). For the inland waterway transportation, the locations and distances between any pair of ports are compiled from the follow:

1) 45 main inland waterways routes (http://viwa.gov.vn)

2) inland waterways routes information (http://cangvudtndhcm.gov.vn)

3) the study of the World Bank (Blancas, L. C., et al., 2013).

The river-road distance between any origin-destination ports are calculated using Dijkstra's algorithm in order to find the length of the shortest path distance.

Table 4.1 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

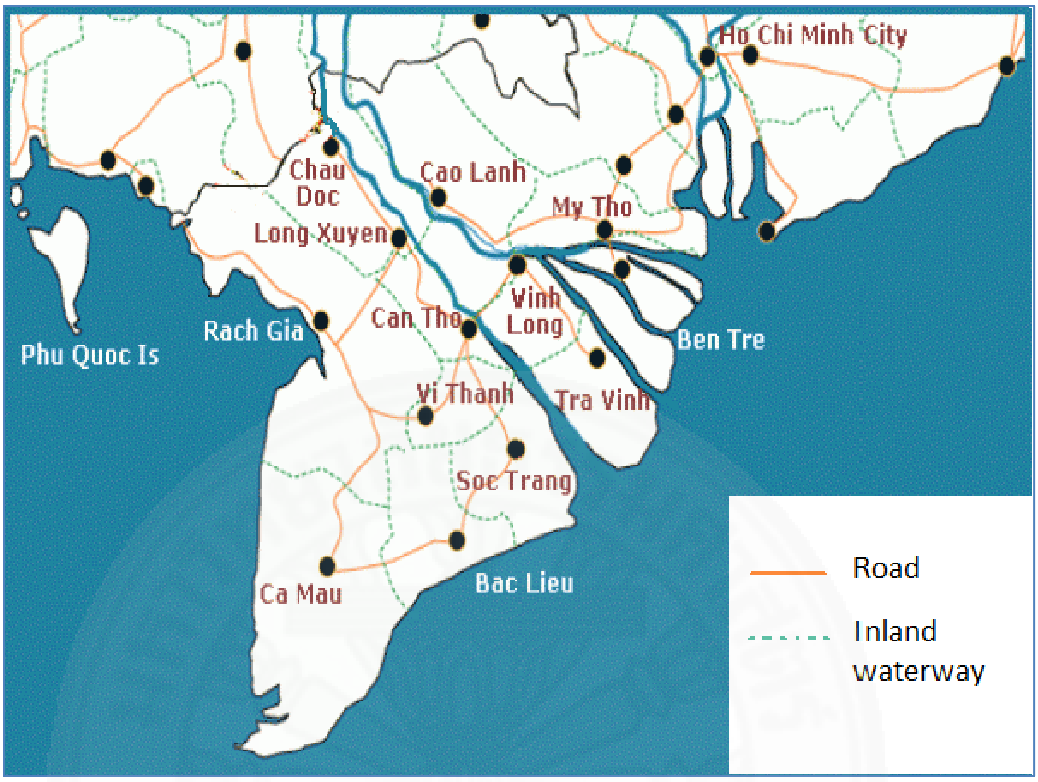

Figure 4.1 The South of Viet Nam transportation network

4.2 Vehicle capacity estimation

The road infrastructure in the South of Viet Nam commonly has tonnage allowance limited to 20 tons per truck (Blancas, L. C., et al., 2013). In terms of ship tonnage allowance, the calculation is based on the data provided in Table 4.2. In Table 4.2, column 1, 2 and 3 are the information for the classes of ship. Column 2 is the tonnage allowance of ship and column 3 is the equivalent number of full truckload. Column 4 (and 5) and 6 (and 7) are the information of the capacity in year 2005 and 2010, respectively. The number of ships in each class (column 5 and 7) can be calculated by dividing the values in column 4 (or 6) with the values in columns 2. Column 8 is the ratio between the number of ships in year 2010 and year 2005. This ratio represents the growth of the popularity of each ship class within 5 years time period.

For the number of ships, it is clear that smaller ships are very popular as the ship class “5-15” and “15-50” outnumber the bigger ship class. However, small ship that is smaller or slightly bigger than one truckload making it unable to achieve economy of scale that is essential in intermodal transportation; therefore, we do not consider these small ships. In terms of the growth rate, it is also clear that ship class 700 and bigger are becoming more popular. The growth from 2005-2010 is 5.49 times for class "700-1000" and 20.47 times for class ">1,000". By following this trend and considering the opportunity to aggregate many truckloads into larger ship, we estimate the ship capacity to be 1000 tons.

Table 4.2 DWT carrying capacity of river vessels by size class in Vietnam

Ship class (ton)	Capacity per ship	Capacity in truckload	Total capacity in 2005	Number of ship in 2005	Total capacity in 2010	Number of ship in 2010	Growth 2005-2010
5-15	7.5	0.4	205,133	27,351	399,293	53,239	1.95
15-50	32.5	1.6	440,668	13,559	776,815	23,902	1.76
50-200	125	6.3	710,375	5,683	1,158,250	9,266	1.63
200-300	250	12.5	200,500	802	312,000	1,248	1.56
300-500	400	20	423,600	1,059	1,195,600	2,989	2.82
500-700	600	30	346,800	578	967,800	1,613	2.79
700-1000	850	42.5	254,150	299	1,394,850	1,641	5.49
>1,000	1,300	65	78,000	60	1,596,400	1,228	20.47

For the ship minimum utilization requirement, RoRo Shipping Company stated that "In order to succeed, you need contracts corresponding to at least 50-60% of the vessel capacity utilization". Based on this statement, we assume that the minimum utilization of vehicle capacity was 50% in this study.

4.3 Cost element estimation

The unit transportation cost in this study consisted of the fixed and variable transportation cost. The unit fixed transportation cost is estimated based on 1) the unit loading/unloading cost per ton and 2) the unit operating wages cost. The unit loading/unloading was estimated to be $2 per ton basing on the fleet operational data, that is collected from “VITRANSS-2” and some inland waterway offices in Vietnam by (Blancas, L. C., et al., 2013). The unit operating wages cost were reported in “Circular No. 261/2016/TT-BTC” from the Ministry of Finance (which also include maritime fees and charges). Table 4.3 combined these data and presented the unit fixed cost of combination for truck and ship. For the variable transportation cost, the data used in this study followed the data as used in (Binh N. T., et al., 2014) that are $0.1 per ton for truck and $0.028 per ton for ship.

Table 4.3 The unit fixed cost for road and inland waterway

Unit fixed cost for truck	**Fixed cost for ship**			
150	3,000	4,500	6,000	7,500
160	3,200	4,800	6,400	8,000
170	3,400	5,100	6,800	8,500
180	3,600	5,400	7,200	9,000
190	3,800	5,700	7,600	9,500
200	4,000	6,000	8,000	10,000

For the emission cost, the unit cost was obtained from the “Vietnam’s government ratified Paris Agreement”. This agreement was an act towards the carbon mitigation goals to help preventing the climate change. To achieve the commitments of the agreement, many countries applied emission trading systems and carbon taxes. Based on the Economic and Social Commission for Asia and the Pacific, the carbon taxes is $10 per ton of CO_2 emission. In addition, the amount of CO_2 emissions per tonmile from truck and ship are obtained from the study of the World Bank (Blancas, L. C., et al., 2013). Using the data from both sources, the unit emission cost used in this research is $0.0005654 per ton for truck and $0.000444 per ton for ship.

4.4 Terminal capacity estimation

Terminal capacity in this study was defined using the loading/unloading capacity in a port which can directly affect the quantity of transferring commodities from one place to another by inland waterway. The capacity of inland waterway port system in the South of Vietnam was planned in "Decision No: 1108/QĐ-BGTVT" of Ministry of Transport (BGTVT,2013). The Table 4.4 presented the terminal capacity.

Table 4.4 Terminal capacity

Node	Name	Capacity (Ton)
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

4.5 Detour factor

Detour factor is used for controlling the delivery time of commodities. In this study, we assume that the first 5 commodities are fresh food that are must be delivered quickly to customer; therefore, roadway was chosen to as a transportation mode. For other different commodities, we allow a detour constraint to limit the additional transportation distance so as to ensure on-time delivery; small detour factor ensure that vehicle choose the short route to transport commodity to customer. The commodities that allow shipment to take a long time, long detour distance may be a better selection to minimize the total cost and do not affect to the deliver time. Detailed detour factors are presented in Table 4.5.

Table 4.5 Detour factor for commodities

Commodity	Detour factor	Commodity	Detour factor
1	-	**16**	1.6
2	-	**17**	1.6
3	-	**18**	1.6
4	-	**19**	1.6
5	-	**20**	1.6
6	1.3	**21**	1.8
7	1.3	**22**	1.8
8	1.3	**23**	1.8
9	1.3	**24**	1.8
10	1.3	**25**	1.8
11	1.4	**26**	2
12	1.4	**27**	2
13	1.4	**28**	2
14	1.4	**29**	2
15	1.4	**30**	2

4.6 The set-up of computational experiment

Twenty-four test instances were created with different unit fixed cost for truck and ship. All computational experiments were run on computer with Intel Core i7 2.6

GHz and 8GB RAM. The ITND model was solved by CPLEX with C++ and Concert Technology (ILOG, Inc.) The study was phased by adding each type of constraints, one at a time, in order to observe their effects. The base model is the full model (3.1) – (3.12) without the terminal capacity (3.7), without the detour constraints (3.8), and without the vehicle utilization (3.9). Model 1 is the base model with the terminal capacity constraints (3.7). Model 2 is Model 1 with the detour constraints (3.8). Model 3 is Model 2 with the vehicle utilization constraints (3.9). Figure 4.2 summarized the step-by-step development of these models, from the base model to Model 3.

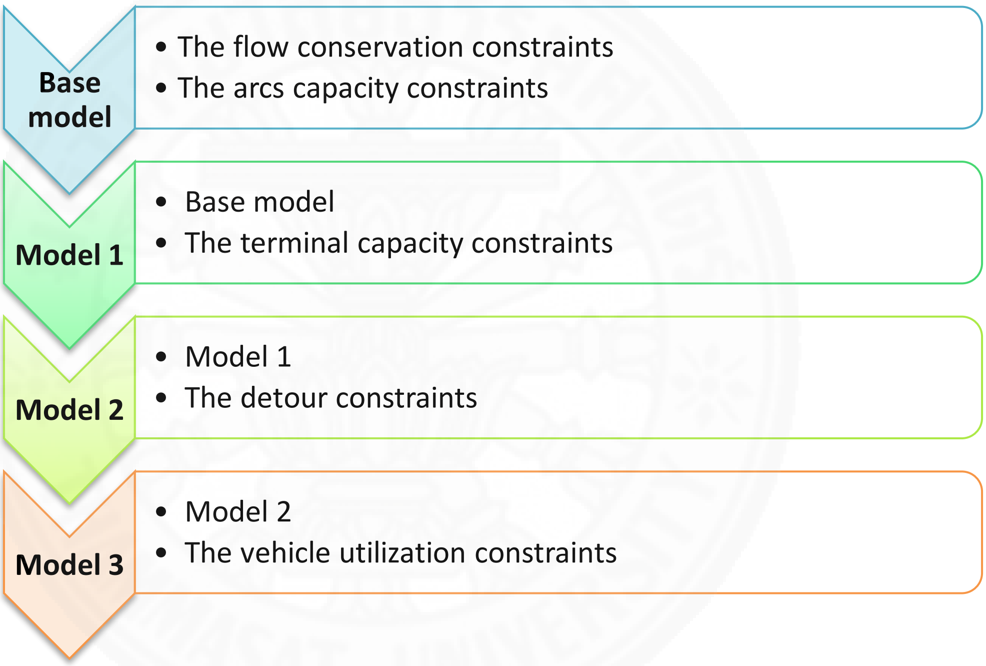

Figure 4.2 Model development

4.7 Computational result

4.7.1 Unimodal and intermodal transportation

In this section, the results of the unimodal and intermodal transportation with roadway and inland waterway (IWW) were evaluated and compared in order to observe the effectiveness of the ITND network.

Table 4.6 Comparing the result of the unimodal and intermodal transportation

Instance	Modal type	Variable cost ($)	Fixed cost ($)	Emission cost ($)	Transfer cost ($)
	Roadway	302,733	161,550	1,711	0
1	IWW	104,084	105,000	1,650	0
	ITND	105,965	97,200	1,602	450
	Roadway	302,733	172,320	1,711	0
5	IWW	105,219	112,000	1,668	0
	ITND	105,965	103,680	1,602	450
	Roadway	302,733	183,090	1,711	0
9	IWW	104,305	119,000	1,653	0
	ITND	105,965	110,160	1,602	450
	Roadway	302,733	193,860	1,711	0
13	IWW	105,219	126,000	1,668	0
	ITND	105,965	116,640	1,602	450
	Roadway	302,733	204,630	1,711	0
17	IWW	105,219	133,000	1,668	0
	ITND	107,161	121,410	1,605	874
	Roadway	302,733	215,400	1,711	0
21	IWW	105,219	140,000	1,668	0
	ITND	107,161	127,800	1,605	874

From the results in Table 4.6, when the unit fixed cost of truck and ship are $150 and $3,000, the variable cost for roadway, inland waterway and intermodal transportation are $302,733, $104,084 and $105,965. In this instance, intermodal transportation is 65% less costly than roadway, and 2% more costly than inland waterway. The variable cost of all instances for roadway transportation are the same when the unit fixed cost increases. For inland waterway, when the unit fixed cost increase, the variable cost also increases. For the intermodal transportation, variable cost increases when the unit fixed cost of truck and ship increase.

In instance 1, the fixed cost of intermodal transportation is $97,200 which is small than 40% and 7% compare to the fixed cost of roadway and inland waterway. The fixed cost of roadway and inland waterway increase when the unit fixed cost for truck and ship increase. For the intermodal transportation, when the unit fixed cost of truck and ship increase from $150 and $3,000 (instance 1) to $200 and $4000 (instance 2), the total cost changes from $97,200 to $127,800, a 31% increase. Hence, the fixed cost has significant effect on total cost.

The emission cost of roadway is not sensitive, even though when the unit fixed cost increases. For inland waterway, the emission cost increases when the unit fixed cost increases. For intermodal transportation, when the unit fixed cost changes from one instance to another, the emission cost fluctuates only slightly. The emission cost of roadway and waterway are higher than the intermodal model which is due to the higher unit emission cost for truck (higher than unit emission for ship). Thus, intermodal transportation can be considered as a more environmental friendly alternative.

The transfer cost is only appeared when the commodity is transferred from one transportation mode to another. It comprises only a very small portion in the total cost. The transfer cost increases slightly when the unit fixed cost increases.

Table 4.7 The total cost of unimodal and intermodal transportation

Instance	Total cost		
	Road	IWW	Intermodal
1	465,994	210,735	205,218
2	465,994	262,087	245,791
3	465,994	315,658	282,352
4	465,994	368,051	313,930
5	476,764	218,887	211,698
6	476,764	274,887	254,571
7	476,764	314,628	284,404
8	476,764	380,546	326,032
9	487,534	224,959	218,178
10	487,534	283,252	263,351
11	487,534	342,540	303,549
12	487,534	402,051	337,982
13	498,304	232,887	224,658
14	498,304	295,887	272,131
15	498,304	354,847	313,989
16	498,304	413,546	349,932
17	509,074	239,887	231,050
18	509,074	306,387	280,911
19	509,074	367,346	324,429
20	509,074	430,486	361,672
21	519,844	246,887	237,440
22	519,844	315,658	289,691
23	519,844	380,546	334,869
24	519,844	446,986	373,382

In the Table 4.7, the total cost of unimodal transportation was higher than the cost of intermodal transportation. In instance 1, when the unit fixed cost for truck and ship are \$150 and \$3,000, the total cost of intermodal transportation is \$205,218, which is 56% less than the total cost for roadway, and 3% less than the total cost for inland waterway. When the unit fixed cost for truck and ship are \$160 and \$8,000, the total cost for intermodal transportation in the instance 8 is 31% less than the total cost for roadway and 14% less than by inland waterway. When the unit fixed cost increases, both the total cost for intermodal and unimodal transportation increase.

In summary, an intermodal transportation model that combines road and inland waterway is more environmental friendly and more economical than the roadway and inland waterway.

4.7.2 Traffic congestion at terminal facilities

The effect of the capacity constraint can be indicated by comparing the base model with Model 1; the result is shown in Table 4.8. The first 3 columns provide the information of the node (terminal locations). Column 4 and 5 are the total traffic of the base model and Model1. It can be seen that the traffic is lowered with the inclusion of capacity constraints, especially for node 7, 10 and 11 where the total traffic is relatively close (or exceed) to the capacity. The total traffic level exceeding the capacity at the terminal node 10 indicates a regular congestion. For terminal node 7 and 11, the total traffic is higher than 88% of the capacity indicates that congestion is very likely to occur especially with the fluctuation of traffic during the day in the busy hours. With the inclusion of capacity constraints, the traffic is now below the capacity for terminal node 10, 11, and below 90% of the capacity for the terminal node 7. The high traffic in node 7 and 11 indicate that the terminal will still be heavily used despite the limited capacity. Therefore, the result suggests a facility upgrade at node 7 to increase the capacity. As an alternative, the capacity parameter V_i can be lowered so that the model would direct some commodities utilizing node 7 to other nodes, and leaving more capacity buffer at node 7.

Table 4.8 The calculated total traffic of the base model and Model 1

Node	Name	Capacity (Ton)	Base model	Model 1
0	Binh Duong	10,000	665	659
1	Dong Nai	15,000	3,692	3,854
2	Vung Tau	20,000	1,293	1,142
3	Ho Chi Minh	24,000	9,956	9,638
4	Long An	19,000	3,136	2,980
5	Tien Giang	3,000	1,339	1,235
6	Ben Tre	2,000	1,755	1,718
7	Tra Vinh	1,500	167	0
8	Vinh Long	3,500	2,325	2,557
9	Dong Thap	2,000	3,064	2,000
10	An Giang/Kien Giang	5,000	4,559	4,775
11	Can Tho	6,000	4,566	4,278
12	Hau Giang	2,000	1,531	1,335
13	Soc Trang	4,000	1,500	1,382
14	Bac Lieu/ Ca Mau	1,000	329	266

4.7.3 Detour factor

In order to see the impact of the detour constraint, the Model 1 and Model 2 (with and without the detour constraints) are tested with the 24 test instances. The results are shown in Figure 4.3, Figure 4. 4, Figure 4.5, and Table 4.9.

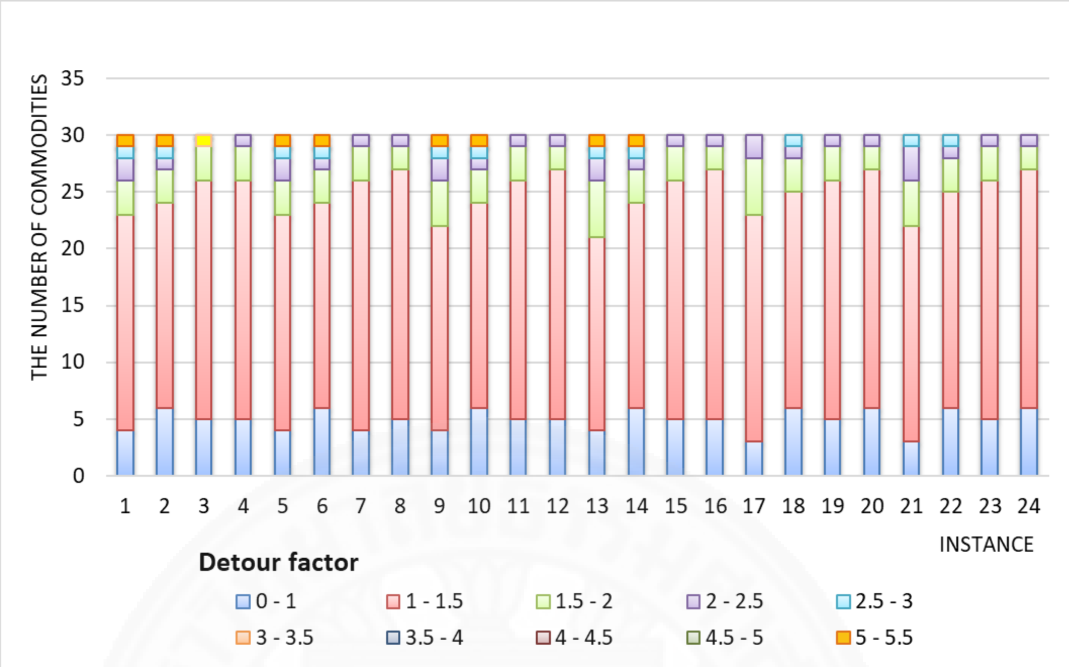

Figure 4.3 The value of detour factor from Model 1

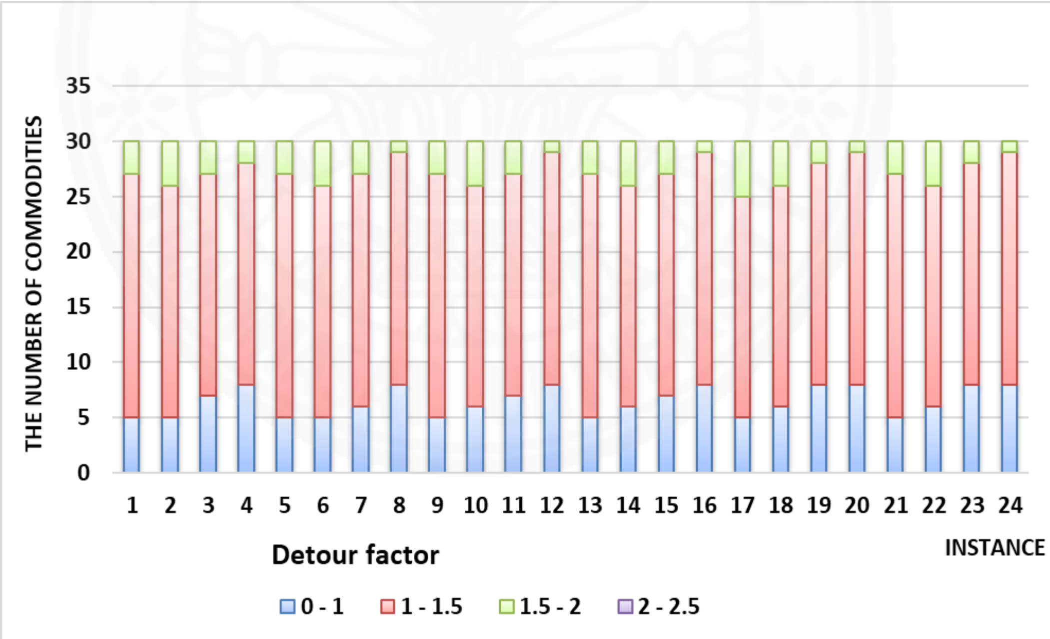

Figure 4.4 The value of detour factor from Model 2

Figure 4.3 shows the results obtained from Model 1 (without the detour constraint). Only 10-20% of the commodities utilize the shortest path to transport the commodities. The majority (50%-60%) of the commodities have the value of detour factor ranged from 1 to 1.5. The rest of the commodities has detour factor above 1.5

and up to 5.5. The high value of detour factor of commodities indicates that the actual route distances of commodity are much longer than the shortest possible distance; hence, the delivery time can be late. In the Figure 4.4, after including the detour constraints, the values of detour factors never exceed 2 (with the majority of 0 - 1.5) indicate that the delivery time of commodities can be controlled.

Detour factor for commodities were summarized in Table 4.9 and Figure 4.5. In Table 4.9, column 1 is the number of test instance. Column 2 (and 4) and 3 (and 5) are the average and the maximum of the calculated detour for Model 1 and Model 2. Without the detour constraints, the average detour ranges from 1.24 to 1.57 with an average of 1.38. The maximum detour in most instances are either 2.12 or 5.19. These values indicate that the majority of the commodities encounter about 40% of additional distance and the detour can be as high as 5.19 in the worst case. On the other hand, with the inclusion of the detour constraints, the average and the maximum detour are significantly lowered. The calculated detours are now within 1.27 (for the average) and 1.50 (for the maximum), which indicates that the detour is kept lower than 28% on average and no more than 100% (maximum of 1.5 is less than 2.0) in the worst case.

Table 4.9 the calculated detour from the Model 1 and Model 2

Instance	Model 1		Model 2	
	Average	**Max**	**Average**	**Max**
1	1.54	5.19	1.28	1.96
2	1.48	5.19	1.27	1.96
3	1.27	2.12	1.23	1.8
4	1.29	2.12	1.21	1.56
5	1.54	5.19	1.28	1.96
6	1.48	5.19	1.28	1.96
7	1.3	2.12	1.24	1.8
8	1.26	2.12	1.18	1.56
9	1.55	5.19	1.28	1.96
10	1.48	5.19	1.26	1.96
11	1.29	2.12	1.24	1.8
12	1.25	2.12	1.17	1.56
13	1.55	5.19	1.28	1.96
14	1.48	5.19	1.26	1.96
15	1.29	2.12	1.24	1.8
16	1.25	2.12	1.18	1.56
17	1.47	3	1.31	1.95
18	1.34	2.75	1.26	1.96
19	1.29	2.12	1.21	1.56
20	1.24	2.12	1.17	1.56
21	1.47	3	1.28	1.96
22	1.33	2.75	1.26	1.96
23	1.29	2.12	1.21	1.56
24	1.24	2.12	1.18	1.56
Average	**1.38**	**3.43**	**1.24**	**1.8**

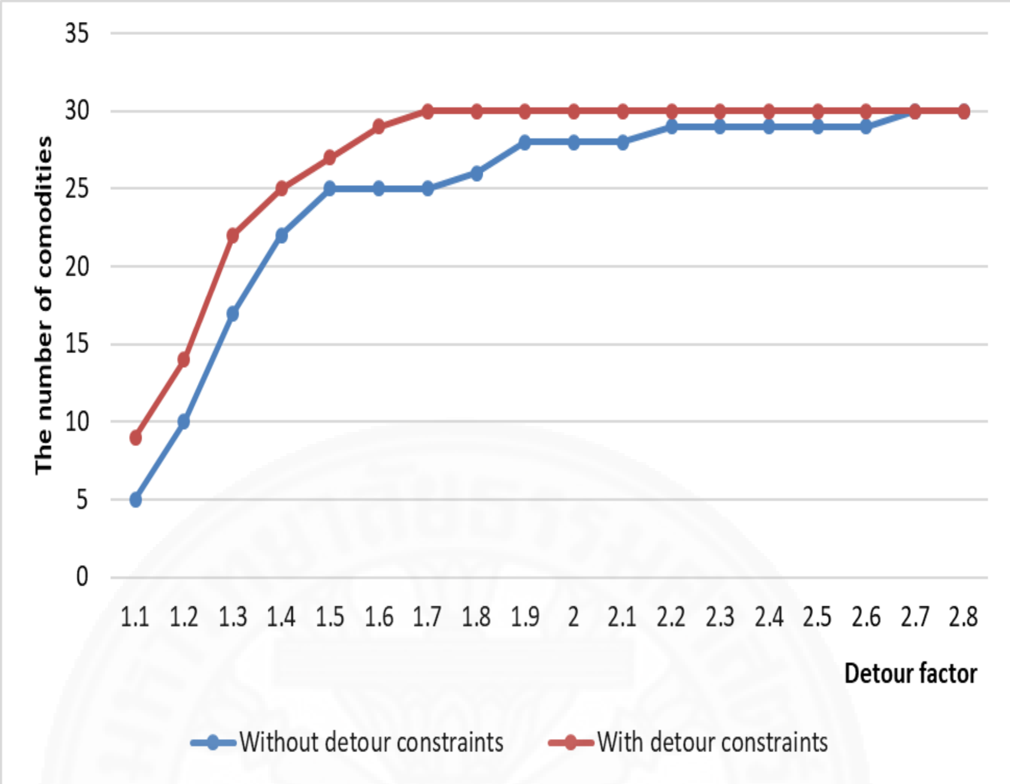

Figure 4.5 Average value of detour factor for commodities from Model 1and Model 2

4.7.4 Capacity utilization of vehicles

The capacity utilization of vehicle is a factor affecting the operation cost of transportation network. The impact of vehicle utilization constraints is shown in Table 4.10. Column 1 is the utilization level of vehicle and Column 2-5 are the number of vehicles with respective utilization level. Base on Table 4.10, Figure 4.6 and 4.7, it is clear that the constraints forced the utilization level of both truck and ship to be higher and more realistic. Without the constraints, the number of truck, whose capacity utilization do not exceed 50%, account for 4%. The number of ship, whose capacity utilization is less than 50%, account for 20%. The utilization may be as low as 20-30% for truck and ship which are not practical for the carriers. This problem can affect the efficacy of operation carriers. When utilization of vehicles become small, the huge investments in large vehicles are less profitable and higher risk. With the constraints, the utilization is then forced to be at least 50%, indicating that vehicles are planned and used more efficiently.

Table 4.10 Comparing the calculated vehicle utilization from the Model 2 and Model 3

Utilization	**Model 2**		**Model 3**	
	Truck	**Ship**	**Truck**	**Ship**
0-10%	0	0	0	0
10-20%	0	0	0	0
20-30%	1	1	0	0
30-40%	1	2	0	0
40-50%	1	2	0	0
50-60%	1	2	1	0
60-70%	1	4	1	0
70-80%	2	5	1	1
80-90%	3	6	2	2
90-100%	26	11	28	7

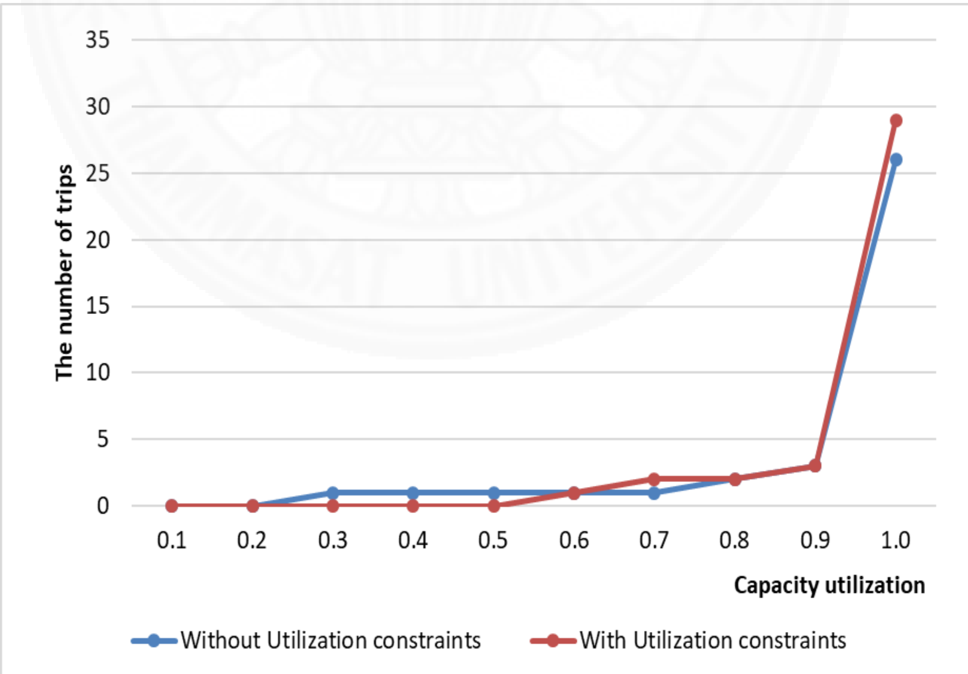

Figure 4.6 Capacity utilization of truck from Model 2 and Model 3

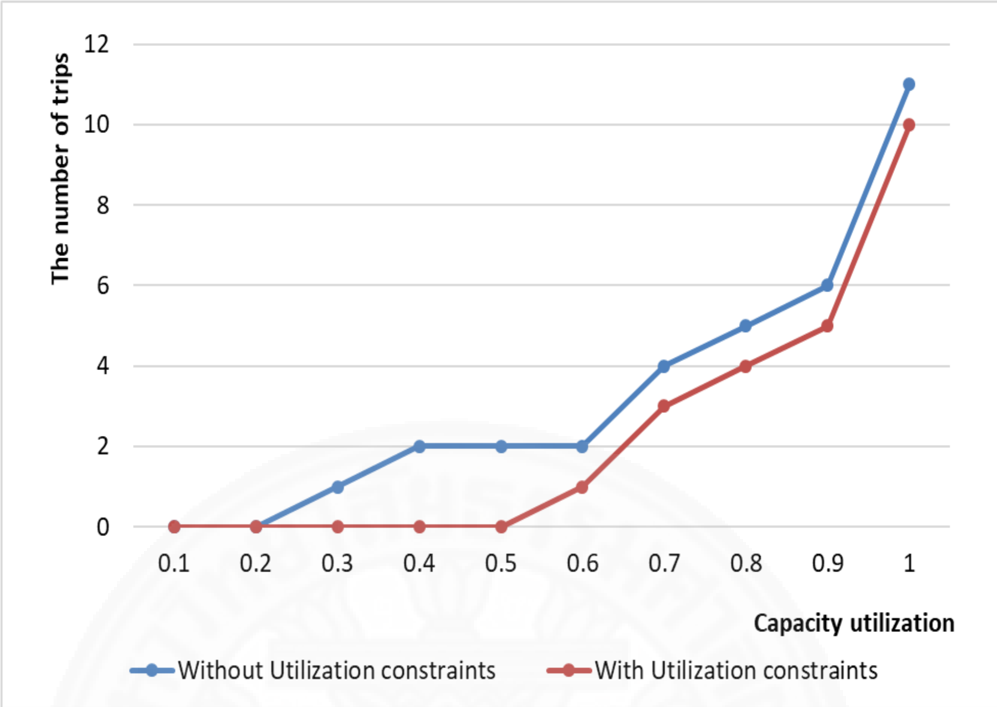

Figure 4.7 Capacity utilization of ship from Model 2 and Model 3

4.7.5 The result from comparing difference models

In order to better see the characteristic of each model, the detailed cost components of the objective function and the calculated detour and vehicle utilization are compared in Table 4.11. In Table 4.11, the total cost and the variable cost are at the lowest in the base model; it is at the highest in the vehicle utilization model. This is due to the fact that the objective function (total cost) is more inferior when the model became more constraint. However, it can be seen that the largest total cost in Model 3 is 20% more expensive than the smallest total cost in the base model. Therefore, the model can better control the transportation without trading off too much of the total cost.

Table 4.11 Comparing the result from difference models

	Base model	Model 1	Model 2	Model 3
Objective ($)	285,050	293,506	344,706	347,416
Variable cost ($)	117,666	122,984	169,299	173,936
Fixed cost ($)	164,343	166,838	171,784	169,904
Emission cost ($)	1,604	1,592	1,607	1,618
Transfer cost ($)	1,437	1,902	1,923	1,957
Minimum detour	1	1	1	1
Maximum detour	5.93	3.43	1.80	1.78
Average detour	1.48	1.37	1.23	1.26
Minimum truck utilization	0.57	0.60	0.47	0.55
Maximum truck utilization	1	1	1	1
Average truck utilization	0.96	0.96	0.96	0.96
Number of truck (unit)	161	204	471	486
Total flows by truck (ton)	3,148	4,025	9,329	9,623
Minimum ship utilization	0.38	0.39	0.44	0.64
Maximum ship utilization	1	1	1	1
Average truck utilization	0.81	0.82	0.82	0.86
Number of ship (unit)	24	23	16	15
Total flows by ship (ton)	19,633	19,009	13,301	13,172

The effects on the variable cost can be observed as follow:

1) the node capacity constraints force the vehicle to travel in a less directed route in order to lower the capacity usage

2) the detour constraints force the transportation to be more directed, but it might come at the cost of using a more expensive vehicle

3) the vehicle utilizations force the consolidation of load onto less number of vehicle, which then cause the load to be transported in a less directed direction.

The fixed cost, on the other hand, is lower in the base Model, but is at the highest in Model 2 (with the detour constraints). In the base Model, the majority of the commodities can be controlled; thus, carriers can easily choose the route to transport commodity while minimizing total cost. The detour constraints have the opposite effect as they force commodities to be transported in a more directed direction which can be different between commodities, and then directly increase the number of vehicles.

The emission cost is lower with the Model 1 (with node capacity constraint) because the capacity constraints discourage the commodities to be transferred in order to avoid overload some nodes. Thus, the commodities are transported in a shorter route and the emission is directly reduced. In Model 3 (with utilization constraint), the emission cost is higher which due to the fact that commodities have to travel longer to a more variety of nodes just to increase the quantity of load and the utilization.

In terms of the transfer cost, it is at the lowest in the base Model as the model are less constrained. This reduces the chance of consolidating multiple commodities onto the same vehicles. The highest transfer cost is in Model 3 (with vehicle utilization) as the constraints increase the amount of commodities on ships, if used, thus increase the transfer.

In addition to the cost terms, the detour and the utilization level are also presented in Table 5. The minimum detour is all the same and equal to 1 (same as the shortest path). The maximum detour and the average detour are lowered for Model 2 (with detour constraints) and the Model 3 (with vehicle utilization) because they have the detour constraints included.

For information on vehicle utilization, every model uses more trucks than ship. Both truck and ship utilization are lowered in the Model 2 (with detour constraints). This results from the attempt to reduce the additional travelling distance which indirectly require more vehicle and, eventually, reduce the utilization. The average truck (and ship) utilization and the number of trucks (and ships) have the reverse relationship. The more the number of vehicles, the smaller the average commodities per vehicle. The number of truck used is largest in Model 3 (with vehicle utilization). This is because the vehicle utilization constraints are applied to both truck and ship. Some commodities that are normally transported by truck now change to ship in order to increase the lower ship utilization.

Chapter 5
Fuzzy Programming for Intermodal Transportation Network Design Model

5.1 Model formulation

In practice, some parameters of intermodal transportation design model such as demand, node capacity or costs are forecasted by experts and are fuzzy. Fuzzy set theory was first introduced by Zadeh, L. A. (1965) and then it was developed and applied to many fields. For the transportation problems, Bit, A. K., et al. (1992) and Verma, R., et al. (1997) used the fuzzy programing technique to solve multi-objective function. Liu, S. T., et al. (2004) and Liu, S. T (2006) developed method that is based on α-cuts to find the fuzzy total cost when the demand and supply quantities, and the unit cost are fuzzy. Basirzadeh, H. (2011) solved fuzzy transportation problem by ranking of fuzzy numbers.

In this study, the node capacity is considered a fuzzy parameter because it depends on efficient operation of resource that changes with time. Therefore, the intermodal transportation design model now becomes the fuzzy intermodal transportation model.

The fuzzy node capacity is represented by $\tilde{V}_i$ and the fuzzy intermodal transportation model is as follow:

$$\begin{aligned}\Xi = \text{Minimize} \quad & \sum_{k\in K}\sum_{(i,j)\in A}\sum_{m\in M} c_{ij}^{m} x_{ij}^{km} d_{ij}^{m} + \sum_{(i,j)\in A}\sum_{m\in M} f_{ij}^{m} y_{ij}^{m} \\ & + \sum_{k\in K}\sum_{(i,j)\in A}\sum_{m\in M} d_{ij}^{m} p^{m} x_{ij}^{km} + \frac{1}{2}\omega \sum_{i\in N}\sum_{k\in K}\left(\sum_{m\in M} z_i^{km} - h_i^k\right)\end{aligned} \tag{5.1}$$

subject to

$$\sum_{j\in N}\sum_{m\in M} x_{ij}^{km} - \sum_{j\in N}\sum_{m\in M} x_{ji}^{km} = b_i^k \qquad \forall i\in N, \forall k\in K \tag{5.2}$$

$$b_i^k = \begin{cases} r^k & i = O(k) \\ -r^k & i = D(k) \\ 0 & \text{otherwise}\end{cases} \quad \text{and} \quad h_i^k = \begin{cases} r^k & i = O(k) \quad \text{or} \quad i = D(k) \\ 0 & \text{otherwise}\end{cases} \tag{5.3}$$

$$\sum_{k\in K} x_{ij}^{km} \le u_{ij}^{m} y_{ij}^{m} \qquad \forall (i,j)\in A, \forall m\in M \tag{5.4}$$

$$\sum_{j\in N} x_{ij}^{km} - \sum_{j\in N} x_{ji}^{km} \le z_i^{km} \qquad \forall i \in N, \forall k \in K, \forall m \in M \tag{5.5}$$

$$\sum_{j\in N} x_{ji}^{km} - \sum_{j\in N} x_{ij}^{km} \le z_i^{km} \qquad \forall i \in N, \forall k \in K, \forall m \in M \tag{5.6}$$

$$\sum_{j\in N}\sum_{m\in M}\sum_{k\in K} x_{ij}^{km} + \sum_{j\in N}\sum_{m\in M}\sum_{k\in K} x_{ji}^{km} \le V_i \qquad \forall i \in N \tag{5.7}$$

$$\frac{\sum_{(i,j)\in A}\sum_{m\in M} d_{ij}^{m} x_{ij}^{km}}{r^k} \le \varepsilon^k S_{O(k)D(k)} \qquad \forall k \in K \tag{5.8}$$

$$\sum_{k\in K} x_{ij}^{km} \le \varphi u_{ij}^{m} y_{ij}^{m} \qquad \forall (i,j) \in A, \forall m \in M \tag{5.9}$$

$$x_{ij}^{km} \ge 0 \qquad \forall (i,j) \in A, \forall m \in M, \forall k \in K \tag{5.10}$$

$$y_{ij}^{m} \in \{0,1,2...\} \qquad \forall (i,j) \in A, \forall m \in M \tag{5.11}$$

$$z_i^{km} \ge 0 \qquad \forall i \in N, \forall k \in K, \forall m \in M \tag{5.12}$$

The fuzzy model can be linearized using decision-making in a fuzzy environment [36] and fuzzy linear programming [37]. Assume that the actual capacity in a node fluctuate 100(1- v)% of the estimated node capacity.

5.2 Defuzzied procedure

For constraints involving the node capacity in problem:

$$t_i \triangleq \sum_{j\in N}\sum_{m\in M}\sum_{k\in K} x_{ij}^{km} + \sum_{j\in N}\sum_{m\in M}\sum_{k\in K} x_{ji}^{km} \le V_i \qquad \forall i \in N \tag{5.13}$$

The corresponding linear membership function of fuzzy node capacity constraint is given as

$$\mu_{V_i}(t_i) = \begin{cases} 1 & t_i < (1-v)V_i \\ \dfrac{V_i - t_i}{vV_i}, & (1-v)V_i \le t_i \le V_i \\ 0 & t_i > V_i \end{cases} \qquad \forall i \in N \tag{5.14}$$

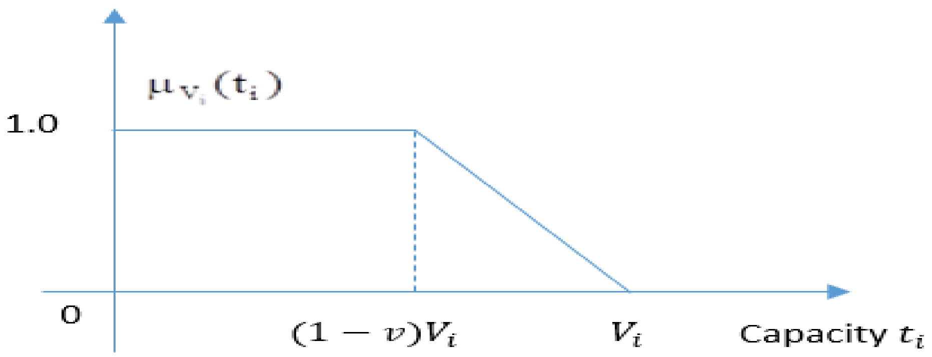

Figure 5.1. A membership function of fuzzy node capacity constraint

The lower bound and upper bound of optimal value are obtained by solving the standard linear programming problems.

$$\begin{aligned}\Xi_1 = \text{Minimize} \quad & \sum_{k\in K}\sum_{(i,j)\in A}\sum_{m\in M} c_{ij}^{m} x_{ij}^{km} d_{ij}^{m} + \sum_{(i,j)\in A}\sum_{m\in M} f_{ij}^{m} y_{ij}^{m} \\ & + \sum_{k\in K}\sum_{(i,j)\in A}\sum_{m\in M} d_{ij}^{m} p^{m} x_{ij}^{km} + \frac{1}{2}\omega\sum_{i\in N}\sum_{k\in K}\left(\sum_{m\in M} z_i^{km} - h_i^k\right)\end{aligned} \tag{5.15}$$

subject to

$$\sum_{j\in N}\sum_{m\in M}\sum_{k\in K} x_{ij}^{km} + \sum_{j\in N}\sum_{m\in M}\sum_{k\in K} x_{ji}^{km} \le V_i \qquad \forall i\in N \tag{5.16}$$

(5.2)-(5.6), (5.8)-(5.12)

and

$$\begin{aligned}\Xi_2 = \text{Minimize} \quad & \sum_{k\in K}\sum_{(i,j)\in A}\sum_{m\in M} c_{ij}^{m} x_{ij}^{km} d_{ij}^{m} + \sum_{(i,j)\in A}\sum_{m\in M} f_{ij}^{m} y_{ij}^{m} \\ & + \sum_{k\in K}\sum_{(i,j)\in A}\sum_{m\in M} d_{ij}^{m} p^{m} x_{ij}^{km} + \frac{1}{2}\omega\sum_{i\in N}\sum_{k\in K}\left(\sum_{m\in M} z_i^{km} - h_i^k\right)\end{aligned} \tag{5.17}$$

subject to

$$\sum_{j\in N}\sum_{m\in M}\sum_{k\in K} x_{ij}^{km} + \sum_{j\in N}\sum_{m\in M}\sum_{k\in K} x_{ji}^{km} \le (1-v)V_i \qquad \forall i\in N \tag{5.18}$$

(5.2)-(5.6), (5.8)-(5.12)

The objective function takes values between Ξ_1 and Ξ_2 while node capacities vary between V_i and $(1\text{-}v)V_i$. Let $\Xi_l = \min(\Xi_1; \Xi_2)$ and $\Xi_u = \max(\Xi_1; \Xi_2)$, then, Ξ_2 and Ξ_2 are the lower bounds and upper bounds of the optimal values, respectively.

The linear crisp problems have finite optimal values. In this case the fuzzy set of optimal values, Ξ, which is a subset of trapezoidal function.

$$\mu(\Xi) = \begin{cases} 1 & \Xi < \Xi_l \\ \dfrac{\Xi_u - \Xi}{\Xi_u - \Xi_l}, & \Xi_l \leq \Xi \leq \Xi_u \\ 0 & \Xi_u < \Xi \end{cases} \tag{5.19}$$

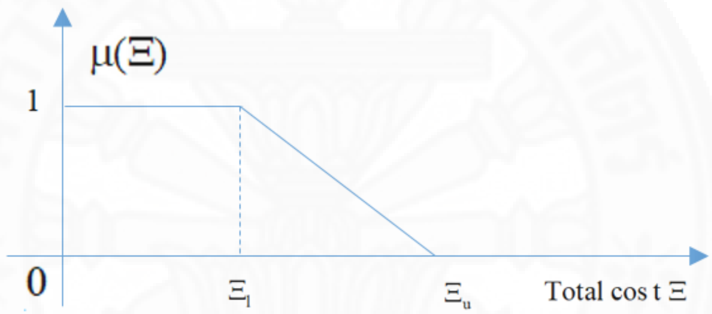

Figure 5.2. A membership function of fuzzy goal for the total cost

Therefore, the fuzzy intermodal transportation model can be converted into the following linear programing model:

$$\text{Maximize} \quad \lambda \tag{5.20}$$

subject to

$$\lambda(\Xi_u - \Xi_l) + \Xi - \Xi_u \leq 0 \tag{5.21}$$

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

$$\lambda v V_i - V_i + \sum_{j\in N}\sum_{m\in M}\sum_{k\in K} x_{ij}^{km} + \sum_{j\in N}\sum_{m\in M}\sum_{k\in K} x_{ji}^{km} \leq 0 \quad \forall i \in N \tag{5.22}$$

$$0 \leq \lambda \leq 1 \tag{5.23}$$

(5.2)-(5.6), (5.8)-(5.12)

5.3 Computational Experiments

Assumed that there is a fluctuation of (1-v)% of the actual capacity, where v = 0.2, 0.3, 0.4 and 0.5. The lower bound and upper bound of the objective value are calculated in the table 5.1.

Table 5.1 The lower bound and upper bound of the objective value

v	Lower bound	Upper bound
0.2	286,261	294,364
0.3	286,261	297,006
0.4	286,261	303,159
0.5	286,261	313,726

The objective values in fluctuation of capacity is presented in table 5.2

Table 5.2 Objective values in fluctuation of capacity

v	Objective (λ)	Total cost($)	Variable cost($)	Fixed cost($)	Emission cost($)	Transfer cost($)
0.2	0.6003	289,500	159,152	124,950	1,645	3,753
0.3	0.5275	291,338	160,645	124,200	1,627	4,865
0.4	0.5513	293,844	162,626	125,100	1,630	4,488
0.5	0.5861	297,629	163,320	129,000	1,641	3,668

From the table 5.2, when v = 0.2, the total costs of fuzzy model are $289,500 that is higher than the total cost of deterministic model of $286,261; each cost term also change slightly. When v = 0.5, the total cost of fuzzy model is $297,629, a 4% increment from the deterministic model. When v increase from 0.2 to 0.5, each cost terms costs and the total cost increase slightly.

Table 5.3 Average value of vehicle capacity and detour factor of fuzzy model

	Deterministic model	Fuzzy model			
		v = 0.2	**v= 0.3**	**v= 0.4**	**v= 0.5**
Average of truck capacity	0.962	0.950	0.939	0.938	0.925
Average of ship capacity	0.759	0.762	0.779	0.771	0.738
Average of detour factor	1.411	1.411	1.305	1.314	1.344

The average value of vehicle capacity and detour factor of fuzzy model is presented in table 4.3. When v increase, the average value of truck decrease slightly and also higher than 0.9. The average value of ship increase when v increase. On the other hand, the average value of detour factor decrease when v increase.

The values of membership function of fuzzy constraints and fuzzy goal are shown in table 5.4.

Table 5.4 Values of membership functions

	v = 0.2	v = 0.3	v = 0.4	v = 0.5
μ_{Ξ}	0.600	0.527	0.551	0.586
μ_{V_1}	1	1	1	1
μ_{V_2}	1	1	1	1
μ_{V_3}	1	1	1	1
μ_{V_4}	1	1	1	1
μ_{V_5}	1	1	1	1
μ_{V_6}	1	1	1	1
μ_{V_7}	0.600	1	1	0.783
μ_{V_8}	1	1	1	1
μ_{V_9}	1	1	1	1
$\mu_{V_{10}}$	0.600	0.527	0.551	0.586
$\mu_{V_{11}}$	1	1	1	0.892
$\mu_{V_{12}}$	0.613	1	0.836	0.597
$\mu_{V_{13}}$	0.875	0.590	0.567	0.619
$\mu_{V_{14}}$	1	1	1	1
$\mu_{V_{15}}$	1	1	1	1

Figure 5.3 Capacity and available capacity (v = 0.2)

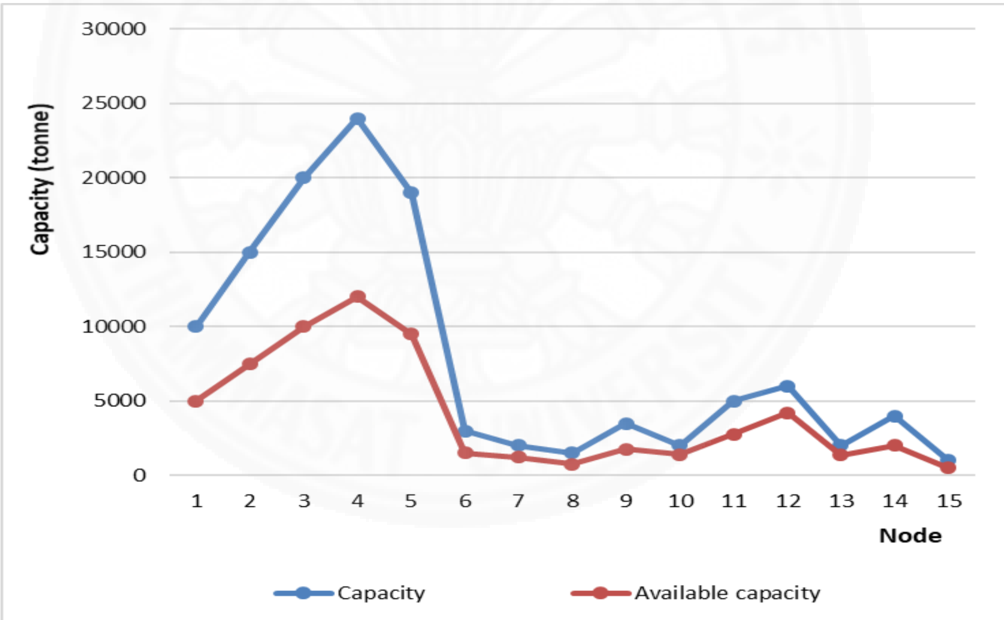

Figure 5.4 Capacity and available capacity (v = 0.5)

The membership function of fuzzy node capacity constraints such that degree of satisfaction will be 1 if the available capacity is within (1-v)100% of node capacity. If the available capacity reaches a maximum limit, degree of satisfaction become 0. In the table 5.4 and figure 5.3 when v = 0.2, each membership degree is equal 1 except for membership degree of node 7, 10, 12 and 13. In table 5.4 and figure 5.4, when v = 0.5, the available capacity of all of nodes smaller than node capacity.

With the fuzzy programming model, we can develop a transportation plan to satisfy customer's demand when capacity is not stable.

Chapter 6
Conclusions and Future research

This research addresses an intermodal transportation network model that consists of the selection of 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, some requirements of stakeholder in network (port agents, customers and carriers) are archived by considering the node capacity, vehicle utilization, and the detour constraints. Based on the results presented above, it can be seen that the intermodal transportation network can be more realistic with the inclusion of the node capacity constraints, the detour constraints, and the vehicle utilization constraints. Without these constraints, the resulting network may have some terminal that is overly used (encounter heavy traffic and congestion). Commodities may have to travel much longer than normal and cause delay in deliveries (large detour level). Vehicle may not be utilized efficiently (low utilization level) and being cost ineffective. By including the constraints, all these limitations can now be better controlled with the expense of increasing the total cost by 20%.

In order to achieve a more reliable network, we incorporated uncertainty for node capacity through the use of fuzzy programing model. The solution procedures are developed to solve the fuzzy linear programing with data from South of Vietnam transportation network. The optimal solution shows that the total cost of fuzzy model is increased by 4% in comparison to the total cost of the deterministic model.

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:

1) More varieties of transportation modes should be considered
2) The number of nodes should be increased to represent large-scale problems
3) Uncertain (fuzzy) cost parameters should be considered.

This research has both theoretical 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.

For the future research, the model can be extended by considering fuzzy cost coefficients and fuzzy demand. Besides, the effect of congestion can be included into the objective function of the model. Moreover, the model can also be applied to another region of Vietnam realistic constraints.

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