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Modeling Transport Costs and Modal Shifts in Freight Transport: A Case of Thailand

By

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Abstract

Shifting freight transport mode from road to others such as rail and waterways has caught attention of policy makers around the world. Policies aimed to encourage and facilitate the modal shift of freight transport have been initiated in several countries. The main arguments for promoting the modal shifts are that rail and waterways are more environmental friendly and more economical than road. This thesis focuses on the cost argument and proposes a method to determine the distance where the modal shifts will between transport modes will be economical. Transport costs in this thesis are determined using a case study of transporting a twenty-foot container from a warehouse in Ampher Nakorn Luang, Ayudhaya Province to Laem Chabang Port to generalize transport costs of road, rail, and inland waterway of Thailand. The result reveals that average transport costs per kilometer are THB 24.33 for road, THB 8 for rail, and THB 7.06 for inland waterway. However, unlike road, rail and inland waterway transport usually requires additional handling activities at transfer nodes and first- and last-mile transport to bridge between user premises and transfer nodes which creates extra costs. As a result, the additional costs of modal transfer are THB 1000 for rail, and THB 1160 for inland waterway, while the cost of bridging transport depends on the distance of between the user premises and the transfer nodes. This thesis proposes a model based on transport costs which is capable for determining the points where different transport modes have equal costs. The model is developed on the basis of traditional cost model but adopts cost data as inputs rather than freight rates, and the model is constructed in a form of linear equation to enable accurate determination of intersects. With the inputs from the case of Thailand, the model suggests that road is the most economical mode for transporting a twenty-foot container for less than 105.93 kilometers, rail is the most economical mode for the distance between 105.93 to 170.21 kilometers, and beyond 170.21 kilometers, inland waterway has the least transport cost when assumes 30 kilometers of bridging transport. Although the model is presented using cost data and figures from the case study, the concept is generalized and thus can be adapted to an analysis in a different context. Finally, the model is applied to an infrastructure development project for railways and inland waterways in order to promote modal shifts of freight transport in Thailand. From the samples of 20 provinces with highest Gross Provincial Product, there will be reductions of more than 20% of transport costs if the freight transport is shifted from road to rail in the routes between Laem Chabang Port and Ayudhaya , Saraburi, Khon Kaen, Nakhon Rajasima, Songkla, Nakhon Pathom, Chiang Mai, Nakhon Sri Dhammarat, Surat Thani, Rajaburi, Khampaeng Phet, and Lamphun and between Bangkok and the following provinces: Rayong, Khon Kaen, Nakhon Rajasima, Songkla, Chiang Mai, Nakhon Sri Dhammarat, Surat Thani, Rajaburi, Kamphaeng Phet, and Lamphun, and from road to inland waterway in the route between Laem Chabang Port and Ayudhaya, Pathum Thani, Nonthaburi, Bangkok, and Samut Sakhon.

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List of Abbreviations

AC_{BT} = Average Total Cost of Bridging Transport

AC_{HD} = Average Cost per Handling

ATC_{mi} = Average Transport Cost of mode i

ATC_{KM} = Average Transport Cost per Kilometer

ATC_{TEU} = Average Transport Cost per TEU per kilometers

ATC_{UKM} = Average Transport Cost per Unit per Kilometer

$BE_{mi,mj}$ = Break-even Point of transport mode 1 and 2

BKK = Bangkok

C_{CAP} = Capital Costs

C_{OP} = Operating Costs

C_{mi} = Constant in Cost Equation of Transport mode i

FEU = Forty-foot Equivalent Unit

GDP = Gross Domestic Product

GPP = Gross Provincial Product

Hrs = Hours

ICD = Inland Container Depot

KM = Kilometers

KM_{BT} = Distance of Bridging Transport in Kilometers

KM_{BTi} = Distance of Bridging Transport in Kilometers of mode i

KM_{H} = Distance of Main haul in Kilometers

KM_{pa} = Total Distance in Kilometers per annum

KM_{T} = Total Transport Distance in Kilometers

LCP = Laem Chabang Port

LKR = Lad Krabang Inland Container Depot

MA = Maintenance Costs
N_U = Number of Units Carried per Haul
N_{BT} = Number of Bridging Transportation
N_{HD} = Number of Handling
N_{TEU} = Number of TEUs
p.a. = per annum
r = Radius
r_j = Radius of node j
TC_{BT} = Total Cost of Bridging Transport
TC_{MT} = Total Costs of Modal Transfer
TEU = Twenty-foot Equivalent Unit
TEUKM = Twenty-foot Equivalent Unit per Kilometer
THB = Thai Baht
TTC/TC = Total Transport Costs
TTC_{TEU} = Total Transport Cost per TEU
TTC_{TEUKM} = Total Transport Cost per TEU per Kilometer
TTC_{UH} = Total Transport Cost per Unit per Haul
X = Distance in kilometers

List of Equations

Chapter 2

(2.1)

$$C(\Upsilon, Pk, Pl, Pt)$$

(2.2)

$$Z = \sum C + \sum T(t) + \sum D$$

(2.3)

$$TTC = Ccap + Cop$$

(2.4)

$$Capital\ Cost = Facility\ Cost + Equipment\ Cost$$

(2.5)

$$\begin{aligned} &Operating\ Cost \\ &\quad = Facility\ Maintenance\ Costs + Equipment\ Costs + Transport\ Costs \\ &\quad + Traffic\ Costs + General\ Costs \end{aligned}$$

(2.6)

$$\begin{aligned} &Cross\ Elasticity\ of\ Demand \\ &\quad = \frac{Percentage\ change\ in\ quantity\ demanded\ of\ product\ A}{Percentage\ change\ in\ the\ price\ of\ product\ B} \end{aligned}$$

Chapter 3

(3.1)

$$Capital\ Cost = Depreciation + Rent + Interest\ Payments$$

(3.2)

$$\begin{aligned} &Operating\ Cost \\ &\quad = Labor\ Costs + Maintenance\ and\ Repair\ Costs + Fuel\ Costs \\ &\quad + Traffic\ Costs + Taxes + Insurance\ Costs + Overhead\ Costs \\ &\quad + Miscellaneous\ Costs \end{aligned}$$

(3.3)

$$TTC = Ccap + Cop$$

(3.4)

$$ATCkm = \frac{TTC}{KMpa}$$

(3.5)

$$ATCukm = \frac{ATCkm}{Nu}$$

(3.6)

$$TTCuh = (ATCukm \times KMt) + TCmt$$

(3.7)

$$TTCuh = \left(\left(\frac{CC + OC}{KMpa} \times \frac{1}{Nu}\right) \times KMt\right) + (Nhd \times AChd)$$

(3.8)

$$ATCteukm = \frac{ATCkm}{Nteu}$$

(3.9)

$$TTCteu = (ATCteukm \times KMt) + TCmt$$

Chapter 4

(4.1)

$$TTCteu = (ATCteukm \times X) + TCmt$$

(4.2)

$$TTC\ teu \begin{cases} ACbt \times X + TCmt; 0 < X \leq a \\ ATCteu - km + Cmi; X \geq a \end{cases}$$

(4.3)

$$TTCteu = (ATCteukm \times X) + (TCmt + TCbt)$$

(4.4)

$$TCbt = ACbt \times KMbt$$

(4.5)

$$BEmi, mj = \frac{Cmi - Cmj}{(ATCmj - ATCmi)}$$

(4.6)

$$Cmi = TCmti + TCbti$$

(4.7)

$$Radius\ (r) = \frac{KMbt}{Nbt}$$

(4.8)

$$Radius\ of\ node\ j\ (rj) = KMbt - KMbti$$

Chapter 1 Introduction

1.1 Background of The Thesis

Shifting of freight transport mode has gained attention from both public and private entities in Thailand for the past several years. As concerns over fuel price, road congestion, and environmental degradation arise, the idea of promoting and encouraging the shift from road to other transport modes that are more cost efficient and environmental friendly, especially rail and inland waterway, has been discussed widely. In the national level, the mode shift of freight transport has been incorporated into the current National Economic and Social Development Plan, which is the national master plan for public policy and investment of the Thai government. This obviously evidences that the mode shift has become a significant issue for public policy on national competitiveness and investment in logistics network.

In the recent years, there are a number of initiatives of mode shifts proposed by private companies and government bodies. Responsible departments and ministries such as Marine Department, Land Transport Department, the Office of Transport and Traffic Policy Planning, Ministry of Transport, National Economic and Social Development Board, and universities have conducted several studies on the freight transport mode shift policy. Private entities also play an important role as they transport their cargoes through railways and inland waterways instead of roads. However, a tool to quantify and compare actual cost benefits between alternative modes of transport has been missing. A vital question arises at this point: What is the optimal distance that the shifting of freight transport mode will be beneficial?

Cost model has been widely adopted to compare total transport costs of several available transport options and multimodal transport. Although the model is useful, it only provides a comparison of freight rates in the available routes. The result provided by the traditional cost model is beneficial for a selection the most appropriate transport route, but not for a decision of where the modal transfer should take place or a comparison of competitiveness of transport modes in a certain route. This decision is essential for both public and private bodies. To promote the use of alternative transport modes other than road, i.e. rail and inland waterway, policy makers have to determine whether the alternative modes have economical advantages over road transport. Otherwise, the policy will be ineffective because the policy is unattractive and irrational to transport users. For private entities, an estimation of distance of the route that the modal shift or transfer is plausible gives a good idea for a project appraisal and feasibility study on location selection of potential facilities.

In this thesis, a case study on transporting a container of rice products from Nakorn Luang – Laem Chabang is selected to determine and model the operational costs of transport. The cost figures will be adopted as inputs in a generalized model which will illustrate intermodal competition in case of Thailand. Although the figures used in the model in this thesis is case-specific, the concept and application of the model can be adopted generally by altering the variables to any routes or countries.

1.2 Research Objectives

The purposes of this thesis are, firstly, to provide a general transport cost structure in case of Thailand. Secondly, to develop a model capable for modeling and compare transport cost of each mode. Thirdly, to use the model to determine the optimal distance that the shifting of freight transport mode will be economical. And finally, to exhibit how the model can be adapted to assist a decision making of and policy on freight transport mode shift and transfer.

1.3 Methodology

A traditional cost model for multimodal transport is adopted to present a comparison between modes of freight transport in the route from Nakorn Luang to Laem Chabang port. Actual transport costs in case of Thailand will be defined and formed a linear cost equation of each transport mode (road, rail, and inland waterway). The definitions of costs are based on findings obtained from literature review. Next, a break-even point of the linear cost equations will be identified using mathematical techniques.

1.4 Data collection

Data on costs is secondary gathered from financial statements, accounting documents, and reports of a port company, a road carrier company, a freight forwarder company, a barge company, Railroad Authority of Thailand, Port Authority of Thailand, Marine Department, and Ministry of Transport. Primary data, such as cost estimation and transit time, is collected using interviews with persons in transport companies and government officials.

1.5 Scope of the Thesis

This is a thesis on total transport cost of shipping a twenty-foot container of rice from a warehouse in Ampher Nakorn Luang, Ayudhya province, until it reaches Laem Chabang Port. The scope begins when the container is ready at the warehouse, transported by several modes, and placed in a container transfer point in a container terminal in Laem Chabang port. The point of origin is a warehouse because in this case, the warehouse in located next to the factory within the same compound. Total transport costs of three modes: road, rail, and inland waterway will be compared and the most economical alternative will be determined. The model development part of the thesis will involve transport cost analysis of freight transport in Thailand, mainly in the routes between the twenty provinces in Thailand with highest Gross Provincial Product (GPP) and Laem Chabang Port and between the twenty provinces and Bangkok.

1.6 Thesis Structure

The thesis composes of seven chapters which can be categorized into four parts. The first part is introduction which includes Chapter 1. The second part is literature review as presented in Chapter 2. The third part is empirical findings and applications which are discussed in Chapter 3, 4, and 5. And finally, the fourth part is conclusion and limitations of the thesis (Chapter 6 and 7).

Chapter one begins with Background of the thesis, research objectives, methodology, scope of the thesis, and background of the case thesis. The aim of this chapter is to provide information on background and foundation of both the thesis and the adopted case thesis.

Chapter two discusses methodologies and concepts found in existing literatures. Characteristics, advantages, and disadvantages of different transport modes are explored to provide fundamental understanding of each mode. Definitions of transport costs are listed and clarified in this part to construct a foundation for the upcoming parts. The traditional cost model is also discussed to evaluate to help develop a new model.

In Chapter three, actual transport costs of each transport mode (Road, Rail, Inland waterway) are defined and discovered. The cost data is adopted as inputs to the modified cost model instead of price to eliminate influence from other factors than operational such as competition level, asymmetric information, and bargaining power. The cost data is used to construct a cost model to validate the alignment of the modified model with the traditional one. Transport costs especially total transport cost and average transport cost per kilometer of Road, Rail, and Inland waterway in case of Thailand are presented in this Chapter.

The new model is developed in Chapter four. In contrast to the traditional cost model, the new model uses transport costs as inputs instead of prices, and the cost function is denoted into a linear equation form to facilitate determination of break-even points of different transport modes. The break-even points are discovered by the model and illustrated. Sensitivity analysis of the model is conducted to observe impacts of changes in the assumption of bridging transport distance on the distance of break-even points.

Chapter five illustrates examples of how the developed model can be adopted to support decisions on transport policy and investment. The model justifies a financial benefit of transport modal shifts in terms of cost reduction, and determines potential locations for transfer nodes.

Chapter six summarized the thesis and a discussion on the main findings. The answers to the thesis questions are concluded again in this chapter. And finally, Chapter seven closes the thesis by drawing limitations of the thesis and suggestions for future research.

Chapter 2 Literature Review

2.1 Transport Modes

There are five modes of transport, namely air, road, rail, water, and pipelines (Chopra and Meindl, 2010; Blauwens et al 2008; Bardi et al, 2006; and Lambert et al, 1998). Air transport is usually the most expensive mode but has the highest speed (Chopra, 2010). For a shipment of which transit time is vital to success of a supply chain such as a supply chain of a high-value, low-volume and density ratio, time-sensitive item, air transport is the best suitable mode that can respond to this specific demand characteristics. However, air transport lacks of flexibility because the service is rather airport-to-airport than door-to-door, which means a completed transport chain of air transport have to includes other modes (multimodal) especially road carriers in order to perform a door-to-door delivery service.

The most common and most popular mode of transport in terms of number of cargoes carried per annum is road transport (Bardi et al, 2006). Unlike other modes, road transport is capable of offering a door-to-door service to users. As a result, road transport has the highest flexibility since it can reach users literally everywhere a road is available. Another advantage of road transport is a competitive price as a result of marginal capital requirement and relatively competitive market. Thus, for the past several decades, road transport has becoming important to development of transport activities in supply chain and logistics operations (Mallard and Glaister, 2008; and Lambert et al, 1998). The most concern on road transport is externality problems including CO2, sulphur dioxide (SO2), nitrogen oxides (NOX), lead, accidents, particulates etc. (Mallard and Glaister, 2008; Chaudhury, 2006, and Bardi et al, 2006)

Although pipeline is the most efficient and has the lowest variable cost per unit carried, the requirement of large sum of investment lessens attractiveness of pipeline transport. In order to provide a completed door-to-door service, an extensive network of pipelines must be laid from origins to destinations. Gas, oil, and water are good examples of products transported by pipelines. The pipeline transport is best suit with products that have continuous flows and in a particular forms; namely liquid or gas. However, pipeline is not suitable with every type of products which poses limitations to its capability. In addition, pipeline is inflexible since the origins and destinations of the network cannot be altered easily without additional investment in the network and infrastructure. As a result, most goods in the world trade are carried by water, road, rail, and air rather than pipeline.

Since the beginning of the industrial revolution, rail transport had driven the world economies and dominated freight and passenger transport for centuries until rail transport lost its popularity in the competition with road carriers in the late twentieth century (Mallard and Glaister, 2008). Rail transport, like air and waterway, offers platform-to-platform (or port-to-port) service rather than door-to-door. Although rail transport requires a significant amount of investment on infrastructure such as rails, stations, signaling devices etc, variable cost per ton-mile of rail transport is lower than road transport because of economies of scale. Significant disadvantages of rail transport are inflexibility, double handling, and initial investment requirement; nevertheless, rail transport is regarded as a more environmental friendly alternative in comparison to road transport.

Water transport can be distinguished into two categories, sea transport and inland waterway transport. Sea transport plays an important role in the world trade and world economies (UNCTAD, 2009). International sea transport is considered as the most economical mode of transport. This is because the modal competition in international transport and logistics is mainly between sea and air, only a small amount of international freight is carried with rail or road as a result of long-haul distance and geographical limitation. Air and sea transport in international environment are thus divided obviously according to product characteristics and user requirements. Inland waterway, on the other hands, is transport within hinterlands and hence faces severe competition with other modes such as road, rail, pipelines or even air.

Inland waterway has the same major disadvantage as air, rail, and sea, which is inflexibility; another mode of transport for first- and last-mile haulage is required in order to complete the transport chain (Rohacs and Simongati, 2007). Inland waterway transport is limited by geographical constraint; it can be done only if there is a waterway such as a canal or a river. Although waterways can be built in theory, it will be very expensive in comparison with laying a railway track or constructing a road. Inland waterway also has additional disadvantages: slow speed, and double handling. Speed of inland waterway transport is slower than that of air, road, and rail. Inland waterway also requires handling at transfer nodes such as ports or train stations to shift transport mode from road or rail to water or vice versa.

The attractiveness of inland waterway in the modal competition arises from the mode’s advantages of low cost per unit carried because of economies of scale, and environmental friendliness (Wiegmans, 2010). Rohacs and Simongati (2007) finds that inland waterway transport has the highest scores in sustainability index which composes of transport operation costs, efficiency, resource use, emission to air, emission to soil and water, noise, and waste. A study by Jonkeren et al (2009) also conducts a simulation and suggests that a decrease in the share of inland waterway transport in the modal split of the European Union that adds the volume of road vehicle kilometers results in an increase in CO2 emission.

2.2 Transport Costs

Lambert et al (1998) states that transport costs can be categorized into two groups: product-related factors and market-related factors. The product-related factors are influenced by the characteristics of the product carried, these factors are: density, stowability, ease of difficulty of handling, and liability.

Density is a weight-to-volume ratio of the product. If the cargo has high weight-to-volume ratio, it is quite heavy compared to the size. Cargoes with low weight-to-volume ratio tend to be more expensive to transport on a one kilo basis because it occupies more space. The second factor is stowability, which is the ability that a product can fill the available space in a vehicle. Because goods are carried in a transport unit, such as a twenty-foot or forty-foot container, products with low stowability requires more transport units to accommodate them. The third factor is ease or difficulty of handling. Products that are easily to handle cost less and thus lead to lower overall transport costs. The final factor is liability. The liability represents the risk that a carrier or a transport operator has to assume. Cargoes with high liability, i.e. high value-to-weight ratio, will be charged with an extra fee.

The second group is market-related factors. These factors are influenced by transport market conditions which are: degree of intermodal and intramodal competition; location of markets; transport distance; nature and extent of government regulations of transport; balance or imbalance of freight traffic; seasonality of product movements; and types of transport i.e. domestic or international.

Mallard and Glaister (2008) classifies transport costs according to their nature as: fixed costs, variable costs, and semi-variable costs. Fixed costs are costs that occur irrespectively of any changes in the number of outputs. Examples of fixed costs are capital outlay, insurance, depreciation, basic administrative costs. Variable costs, on the other hands, vary with the level of output or the number of cargoes carried in this case. Examples of variable costs are: fuel costs, wear and tear, toll charges etc. lastly, semi-variable costs are “fixed over a certain range of output, but then change once the upper limit of the range is reached” (Mallard and Glaister, 2008). Examples of semi-variable costs are component parts i.e. tyres and batteries, and labor costs.

A cost structure of sea transport in (Mallard and Glaister, 2008) can be adapted to inland waterway transport because both sea and inland waterway share similar characteristics and operational requirements such as assets (ports, navigational ways and equipments), and handling procedures (loading, discharging). The fixed costs thus are capital outlay, insurance, basic administrative charges. The variable costs are fuel, wear and tear, habour fees, and in-voyage provisions. Finally, the semi-variable costs are components and labour costs.

Oum (1979) mentions in his paper that a cost function for freight transport can be classified as

$$C(\Upsilon, Pk, Pl, Pt)$$

(2.1)

Where P_K is a rental price of capital,

P_L is a price of labor, and

P_T is prices of freight transport services

Lingaitiene (2008) proposes that a function of transport costs is:

$$Z = \sum C + \sum T(t) + \sum D$$

(2.2)

Where Z represents the total costs of transport; C is technological costs of transport; T (t) is the total time expenses; T is time of transport, loading, and storage; t is relative expenses in terms of time; and D is insurance expenses. Technological transport costs can be represented in an equation as follows:

Technological transport costs compose of fuel costs, oil or other maintenance materials, costs of maintenance and repairs, road or railroad or port taxes, transport equipment insurance costs, drivers' payment, and cargo forwarding expenses.

There are also three equations for transport cost model found in Butler et al (1996) which are:

$$Total\ Transport\ Cost = Capital\ Costs + Operating\ Costs$$

Or

$$TTC = Ccap + Cop \tag{2.3}$$

Where,

$$Capital\ Cost = Facility\ Cost + Equipment\ Cost \tag{2.4}$$

$$\begin{aligned} Operating\ Cost \\ &= Facility\ Maintenance\ Costs + Equipment\ Costs + Transport\ Costs \\ &+ Traffic\ Costs + General\ Costs \end{aligned} \tag{2.5}$$

Capital costs are costs of investment in initial infrastructure such as road construction, railroad track construction, port constructions, etc. Operating costs are costs of providing transport services. Facilities costs are investment in routes, structures, and terminals. Equipment costs are investment in vehicles and equipments. Facility maintenance costs are costs of maintaining motive power and rolling stocks i.e. trucks, boats, etc. Transport costs are costs of conducting transport i.e. power and fuel, wages of vehicle crew, wages of administrators such as persons directing movements of vehicles. Traffic costs are costs of traffic solicitation, wages of highway safety officers, advertising, publishing rates and tariffs, and administration. And finally, general costs are costs of general office expenses, legal advice, accounting, and salaries of general offices and staffs.

2.3 Transport Mode Selection

Jeffes and Hills (1990) conduct a research to explore what are determinants on mode choices of freight carriers in the United Kingdom. The result shows that in a microeconomic level, mode choices are subject to group decisions, customer requirements, price and budget constraint, urgent deliveries, transport infrastructure, company policy, and production level. Group decisions are the decisions made by the transport companies to determine the type of transport modes that will be used. To a large extent, customer requirements also play an important role since customers may specify they preference or requirement on one or more mode choices in relative with their product characteristics such as time-sensitivity and urgency. Transport infrastructure means the availability and quality of existing infrastructure such as the presence, easiness, and accessibility of railways, canal network etc. for transport companies themselves, Jeffes and Hills (1990) find that the most significant determinants for mode choices are reliability of transport mode, control over dispatch, control over delivery time, avoidance of damage to product when in transit, security of product in transit, transit time, and ready availability of transport when required.

Matear and Gray (1993) summarizes factors determining transport modes as the level of demand, the length of haul, characteristics of transported commodity, special offers, speed of transport (transit time), damage to the consignment, reliability of the carrier, characteristics of the transport mode, characteristics of the transport decision maker, route (frequency, capacity, convenience, directness, and flexibility), costs (freight rate and other related costs), and service factors (delays, reliability and urgency, damage avoidance, los and theft, a fast response to any problems, co-operation between the shipper and the carrier, documentation and tracing ability).

In a study on mode choices of a modal competition in the route between Rotterdam and Duisburg, Ribbink et al (2005) concludes that there are two major factors influencing the choices between three modes of transport: road (freeways), water (River Rhine), and rail (Betuweline). The two major factors are transit time and costs. Ribbink et al (2005) also discovers that the decision on mode choices can be distorted by the market failure since the total costs of using road transport does not include externality costs such as light pollution, air pollution, accidents.

The literature shows that transport cost and transit time of the modes in the same route are the critical, if not the most important, success factor in determining the “winner” in the intermodal competition. Ribbink et al (2005) provides a good example of how transport costs can influence user’s decision on mode choices and thus effect the competition between modes of transport. The cost analysis and comparison between transport modes will be adapted to this paper to illustrate the intermaodal competition in the case study.

2.4 Modal Competition in Freight Transport

In general, the demand for transport is determined by price, availability, and quantity of substitute products; price, availability, and quality of complementary products; income changes; population changes; popularity effects; speed; reliability; bureaucracy; and security (Mallard and Glaister, 2008). The competition between modes of transport mainly occurs as the presence of the price, availability, and quality of complementary products. There are two types of modal competition, intra-modal and inter-modal competition. Intra-modal competition means a competition within the same mode of transport i.e. competition between road carriers, shipping companies, or airlines. Inter-modal competition occurs when there are more than one alternative to transport goods from an origin to a destination, consequently, each mode in the same route compete with each other to capture the demand for transport or the cargoes. Although the inter-modal competition can refer to a competition between all modes of transport, this paper is limited to the competition between two modes of transport: road and inland waterway.

Inter-modal competition in freight transport also involves cross elasticity of demand for a particular transport mode. The cross elasticity of demand represents the relationship between a change in quantity demanded of product A and a change in the price of product B (Mankiw, 2009).

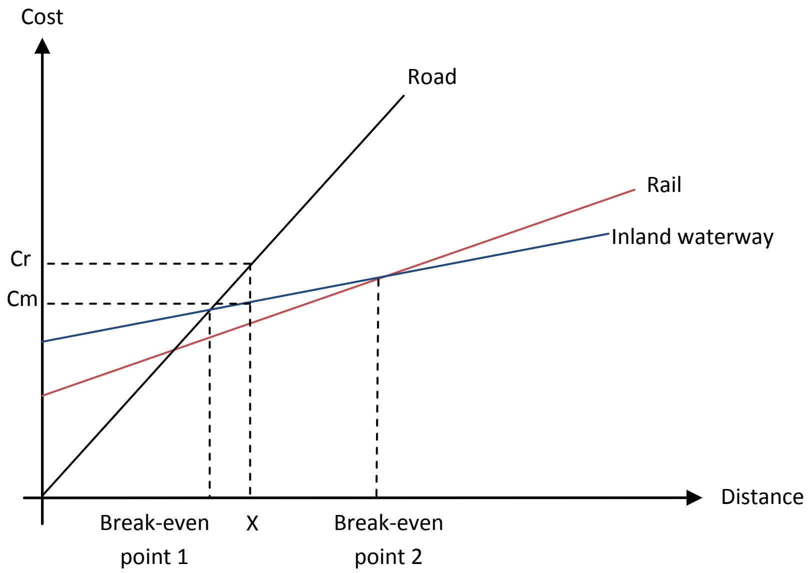
$$\begin{aligned} &Cross\ Elasticity\ of\ Demand \\ &\qquad = \frac{Percentage\ change\ in\ quantity\ demanded\ of\ product\ A}{Percentage\ change\ in\ the\ price\ of\ product\ B} \end{aligned} \tag{2.6}$$

A positive value of the cross elasticity of demand indicates that the two products are substitutes because the quantity demanded of product A increases as the price of product B increases. On the other hands, a negative value of the cross elasticity of demand suggests that the two products are complementary as an increase in the price of product B results in an decrease in quantity demanded of product A. Oum et al. (1990) estimates cross elasticity of demand of different transport modes. The results reveal that, in freight transport, rail and road are substitutes while rail and waterways are complements. As a result, a competition exists between road and rail transport or road and waterways rather than between rail and waterways.

2.5 The Traditional Cost Model

The cost model, as originally proposed by Beresford (1999) and later developed by Banomyong (2004), tries to examine and quantify the total cost and cost per distance of transporting a particular product in a particular route. The model proposes that each mode of transport has different cost characteristics. For example, road transport has lower cost at zero kilometer than rail or water but has higher variable cost per distance carried. As a result, road transport is cost competitive in a range of distance before the cost curve of road transport intersects with a cost curve of another mode. The intersection point between two mode cost curves is the break-even point where it is more economical to shift the transport mode to another mode that has lower cost per distance and thus presents lower overall cost than using only one transport mode.

Figure 2.1 Unimodal alternatives (road, rail, and water)

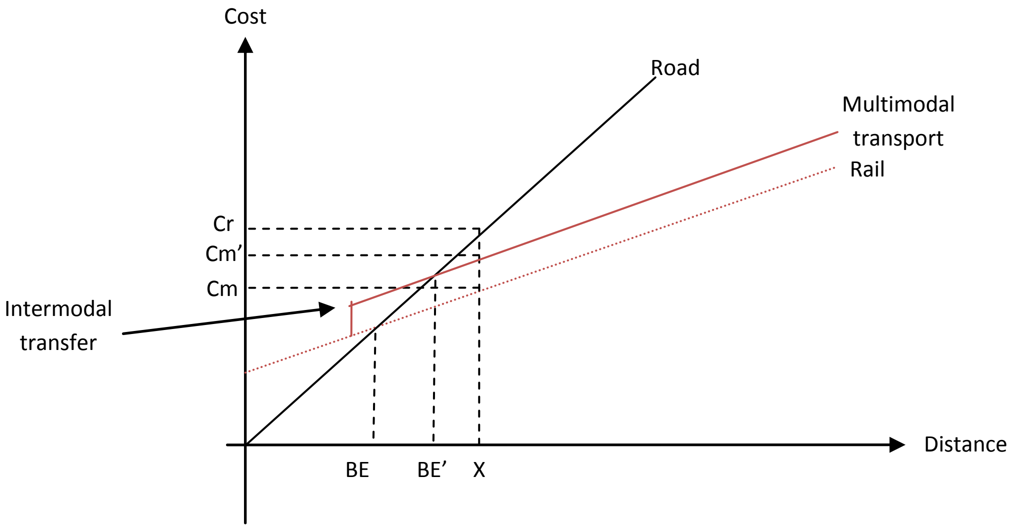


Source: adapted from Jonkeren et al (2009)

Figure 2.1 illustrates the cost curve of different transport modes. At the zero distance, the origin point on the cost axis represent fixed costs of each transport mode. Road transport has the lowest fixed cost because it requires relatively only marginal investment in capital, mainly trucks and chassis. The fixed cost of rail transport is higher because of the initial investment in locomotives, terminals, and rolling stocks. In this case, it is assumed that investments in infrastructure such as highways and rail tracks are done publicly. Water transport has the highest fixed cost because of larger initial capital requirement in ships, terminals, handling equipment.

The steep of the cost curve shows the amount of total cost per distance. This cost is calculated by dividing the total cost with distance carried where the total cost is the summation of fixed and variable costs. The cost curves of rail and water have fewer slopes than that of road as a result of economies of scale. Figure 2.1 shows that it will be more economical and cost effective to use road transport until the break-even point 1 is reached, the shift the transport mode to rail to reap the benefits of economies of scale over longer haulage distance. This decision is very rational since the total cost will be higher if the road transport continues. For example, at the X distance, the total cost of using all-road transport is Cr, while the total cost of multimodal transport of road and rail is Cm (this is in the absence of cost occurring at the intermodal transfer point such as handling cost).

Figure 2.2 Combined transports (road-rail)



Source: adapted from Jonkeren et al (2009), Macharis and Pekin (2008), Banomyong (2004), and Beresford (1990)

With the presence of cost at intermodal transfer point, the rail cost curve shifts upward and becomes a multimodal transport cost curve. Examples of the transfer costs are handling costs, terminal fees, surcharges etc. (Banomyong, 2000). Ceteris paribus, the total cost of transporting a unit of cargo at the X distance increases from Cm to Cm' and the break-even point moves rightward from BE to BE'.

A notification at this point shall be made that there are four main factors affecting the total cost of the transport: fixed cost, variable cost per distance, transfer cost, and distance. The fixed cost, in this sense means the costs that do not vary by distance, determines the Y-axis intersection point. The variable cost determines the slope of the cost curve and thus the position of the break-even or transfer point on the X axis. The transfer cost shifts the cost curve upward hence increase distance of the break-even point. And finally, the distance determines whether a transport mode or a combination of transport modes is feasible for a certain shipment.

The use of the cost model to compare alternatives between combinations of transport modes has been found in a number of literature, such as Banomyong (2004), Banomyong (2000), Beresford (1999), Beresford and Dubey (1990). For instance, Banomyong (2004) adopts the cost model to compare the total cost of multimodal transport of a twenty-foot container of wine from Marseilles to Vientiane in three routes. Beresford (1990) uses the cost model to provide information and comparison on distance, cost, and transit time of the three alternatives routes from London to Thessaloniki in Greece.

Although this paper adopts the same principle of using the cost model to compare two alternatives between road and inland waterway transport, the focus of the thesis is highly on the operational cost analysis of road, rail, and inland waterway and ways to facilitate and encourage the shifting of transport mode away from road in Thailand in corresponding to Thai government policy.

In addition, one common input of the cost model in every literature is the price offered by transport service providers, not the cost of the carriers. Even though it can be argued that freight rates represent the cost to shippers or cargo owners, it does not provide much information or benefits in terms of public investment to policy makers because the price can be influenced by other factors than operations such as profits from uncompetitive market structure. Consequently, this paper will use actual cost of transport to provide a substantial cost analysis for government policy on modal shifts and intermodal transport.

Other drawbacks of the traditional cost model is that it provides a comparison of different choices of routes and modes of transport, but not the suggestion of where the modal shift will be economical to take place. This paper will modify the traditional cost model to find the break-even point where each mode intersects and thus is the optimal distance where the transport mode can be shifted. This is important to government and policy makers in an attempt to indicate an ideal location of a transfer node of transport modes. Another disadvantage of the traditional cost model is that the model does not take inventory cost into account, despite the fact that different transit time has different impact on inventory level and hence inventory-related costs. But because of time limitation, the inventory issue will not be included in this thesis.

Chapter 3 Determining Freight Transport Costs of Thailand

3.1 Chapter introduction

In this thesis, modified cost components are developed from Lingaitiene (2008) and Butler et al (1996). The modified composes of the following inputs:

$$Capital\ Cost = Depreciation + Rent + Interest\ Payments \tag{3.1}$$

$$\begin{aligned} Operating\ Cost & \\ &= Labor\ Costs + Maintenance\ and\ Repair\ Costs + Fuel\ Costs \\ &+ Traffic\ Costs + Taxes + Insurance\ Costs \\ &+ Overhead\ Costs + Miscellaneous\ Costs \end{aligned} \tag{3.2}$$

Where Labor costs include Salaries, Bonuses, Overtime, and others expenses. Maintenance and repairs costs are a function of Lubricants, Tires, Parts and supplies, and others related expenses. Example of Traffic costs are tolls, congestion charges, parking charges, etc. Overhead costs are costs occurring from supporting activities such as accounting expenses, administration expenses, sales etc.

With above input variables, a model can be formulated suggesting that total transport cost per unit per haul is derived from:

$$Total\ Transport\ Cost = Capital\ Costs + Operating\ Costs$$

Or

$$TTC = Ccap + Cop \tag{3.3}$$

Thus, average total transport cost per kilometer can be denoted as:

$$Average\ Transport\ Cost\ per\ km = \frac{Total\ Transport\ Cost}{Total\ Kilometers\ per\ annum}$$

Or

$$ATCkm = \frac{TTC}{KMpa} \tag{3.4}$$

$$Acerage\ Transport\ Cost\ per\ unit\ km = \frac{Average\ transport\ cost\ per\ KM}{Number\ of\ units\ per\ haul}$$

Or

$$ATCukm = \frac{ATCkm}{Nu}$$

(3.5)

$$\begin{aligned} &Total\ Transport\ Cost\ per\ unit\ per\ haul \\ &\quad = (Average\ Transport\ Cost\ per\ unit\ km \times Total\ Distance) \\ &\quad + Total\ Cost\ of\ Modal\ Transfer \end{aligned}$$

Or

$$TTCuh = (ATCukm \times KMt) + TCmt$$

(3.6)

Where handling costs per unit per haul can be found by: dividing total handling costs by number of units, or multiplying handling cost per unit with number of handlings per unit.

As a result, the total transport cost equation can be generalized to:

$$\begin{aligned} &Total\ Transport\ Cost\ per\ unit\ per\ haul \\ &\quad = \left(\left(\frac{Capital\ costs + Operating\ Costs}{Total\ Kilometers\ per\ annum} \times \frac{1}{Number\ of\ units\ per\ haul}\right)\right. \\ &\quad \left. \times Total\ distance\ in\ KM\right) \\ &\quad + (Number\ of\ Handling \times Average\ Cost\ per\ Handling) \end{aligned}$$

Or

$$TTCuh = \left(\left(\frac{CC + OC}{KMpa} \times \frac{1}{Nu}\right) \times KMt\right) + (Nhd \times AChd)$$

(3.7)

The unit of transport can be altered to various measurements i.e. ton or TEU. In this thesis, the unit illustrated in the case study is a TEU; therefore, the formulas are applied as:

$$Average\ Transport\ Cost\ per\ TEU\ km = \frac{Average\ transport\ costs\ per\ km}{number\ of\ TEU\ carried\ per\ haul}$$

Or

$$ATCteukm = \frac{ATCkm}{Nteu} \tag{3.8}$$

$$\begin{aligned} &Total\ Transport\ Cost\ per\ TEU\ per\ Haul \\ &\quad = (Average\ Transport\ Cost\ per\ TEU\ km \times Total\ Distance) \\ &\quad + Total\ Cost\ of\ Modal\ Transfer \end{aligned}$$

Or

$$TTCteu = (ATCteukm \times KMt) + TCmt \tag{3.9}$$

The total Costs of Modal Transfer per unit per haul are equal to handling costs at transfer nodes and other related costs such as bridging transport. Handling costs can be found by: dividing total handling costs by number of TEU, or multiplying handling cost per TEU (or lift) with number of lifts per TEU.

At this point, a case study of transporting a container from a warehouse in Ampher Nakorn Luang, Ayudhya province to Laem Chabang Port via road, inland waterway, road/rail, and rail is selected to determine the transport costs.

3.2 Freight Transport in Thailand

3.2.1 Overview of Modal Splits

Table 3.1: Quantity of cargo carried by each transport mode in thousand tons

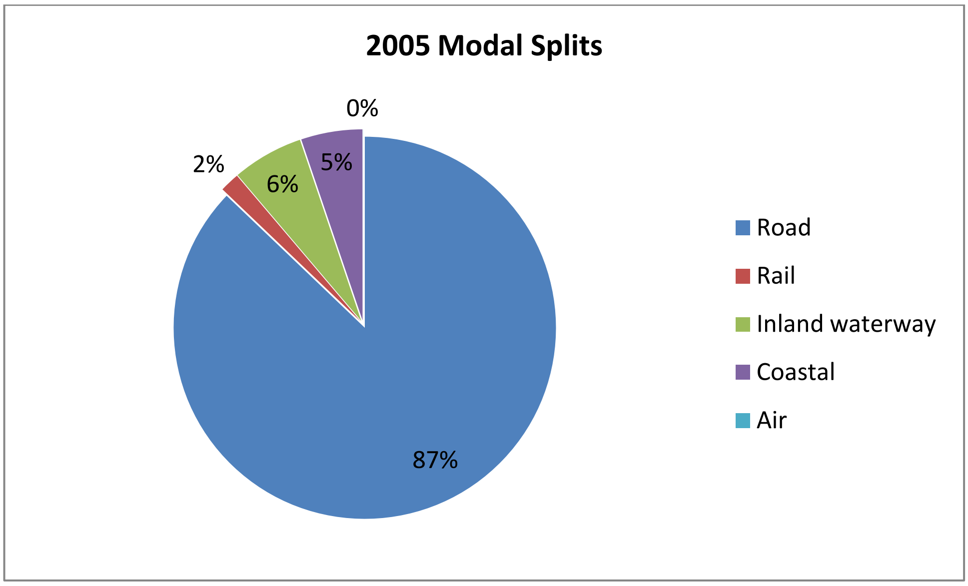
in thousand tons

Modes	1999	2000	2001	2002	2003	2004	2005
Road	392244	397976	400241	434918	440018	435147	430275
Rail	9264	9171	8776	8893	10521	12883	8200
Inland waterway	17910	25235	17833	25043	25839	26825	29630
Coastal	21970	23347	19657	24795	22941	25862	25625
Air	56	57	66	56	54	53	39
Total	441444	455786	446573	493705	499373	500770	493769

Modes	1999	2000	2001	2002	2003	2004	2005
Road	89%	87%	90%	88%	88%	87%	87%
Rail	2%	2%	2%	2%	2%	3%	2%
Inland waterway	4%	6%	4%	5%	5%	5%	6%
Coastal	5%	5%	4%	5%	5%	5%	5%
Air	0%	0%	0%	0%	0%	0%	0%

Source: adapted from Ministry of transport (2006b)

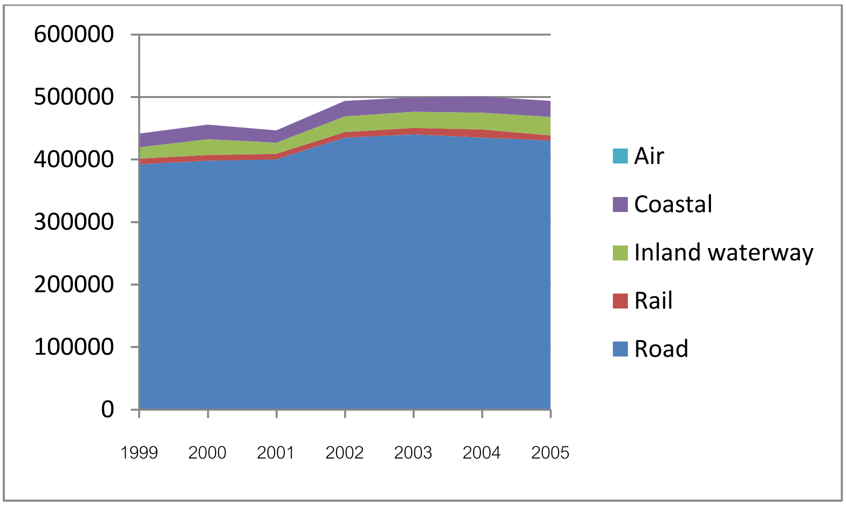
Figure 3.1 Thailand's modal splits for freight transport 2005



Source: adapted from Ministry of transport (2006b)

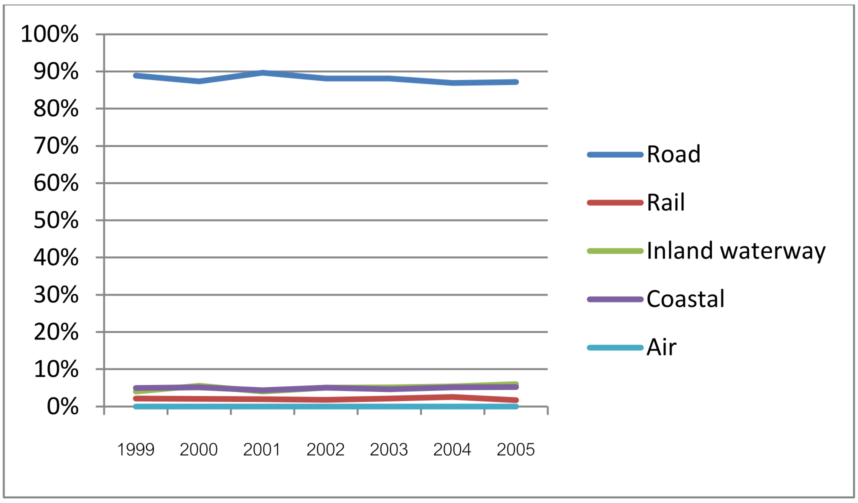
Thailand can be considered as a road economy. In 2005, approximately 87% or 494 million tons of total cargos are transported by road and this trend lasts for at least seven consecutive years as from 1999 to 2005. In the period between 1999 and 2005, there is no a single year that the proportion of road freight transport is lower than 87%. Inland waterway accounts for 6% in 2005 followed by coastal shipping at 5% and rail at only 2%. This substantial dependence on road transport raises an issues for Thai government and policy makers to take course in encouraging modal shifts form road to other transport modes especially inland waterway and railway which are more cost competitive and environmental friendly (Marine department, 2010). The modal shift issue has been incorporated in the tenth national economic and development plan (2007-2011) (National Economic and Social Development Board, 2010). However, a solid and concrete roadmap and key performance indicators have not been set up to track and encourage the modal shifts. According to the Harbor Department's annual plan 2010 (Harbor Department, 2009), almost all the works claimed to assist and encourage modal shifts toward inland waterway involve construction and civil projects such as harbor construction, quay wall construction, break water construction, none of them concern with economic tools or policy (it is worth to mention that the harbor department, or sometimes known as the water transport and maritime department, is responsible for all water transport activities including sea and inland waterway). At the more aggregate level, namely the Ministry of transport and the National Economic and Social Development Board, measures and policies aimed to promote modal shifts and encourage inland waterway and rail transport have already been discussed for several years and a number of studies have been done. Unfortunately, the statistics and government's plans evidence the fact that it is nothing more than just a lip service, not an actual course of action.

Figure 3.2 Thailand's modal splits for freight transport 1999 – 2005 (in thousand tons)



Source: adapted from Ministry of transport (2006b)

Figure 3.3 Percentage of Thailand's modal splits for freight transport 1999 – 2005



Source: adapted from Ministry of transport (2006b)

3.2.2 Road Freight Transport in Thailand

Thailand has an extensive road network of more than 100,000 kilometers. There are four bodies responsible for road construction and maintenance: two departments in the ministry of transport (department of highways and department of rural roads), local municipalities, and private bodies (through concession) (Ministry of transport, 2006). The number of truck operators is also high, Department of Land transport (2010) reports that in 2009 there are 791,414 trucks registered with the department carrying 424 million tons or 179,000 million ton-kilometers with an average haulage distance is 409-435 kilometers.

It can be seen from the Appendix III that the most congested routes are the major highways linking large cities such as Bangkok with industrial area i.e. Ayudhya, Chonburi, Rayong and deep sea port i.e. Laem Chabang. The congestion of highways poses importance on alternative modes of transport such as inland waterway and rail. The congestion issue is not surprise considering that approximately 87% of freight transport in Thailand is carried through roads, compared to 75% in the European Union (Wiegmans, 2010).

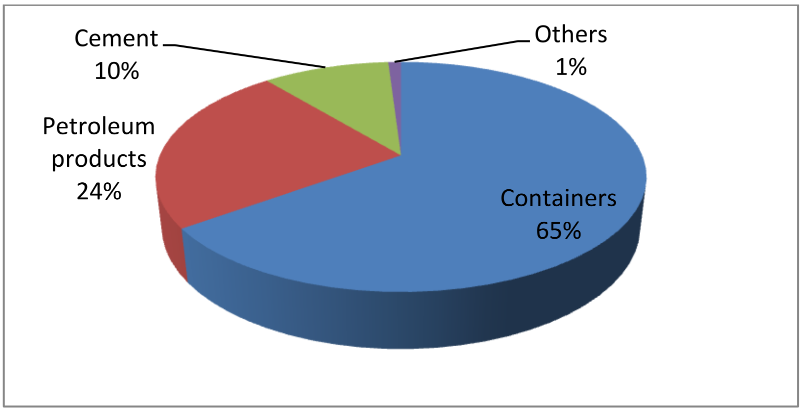
3.2.3 Rail Freight Transport in Thailand

There are 4,180 kilometers of railways connecting 46 out of 76 provinces in Thailand. 3,901 kilometers or 93.3% of the railways are single tracks, 220 kilometers or 5.3% are double tracks, and 59 kilometers or 1.4% are triple tracks. All tracks are meter gauge (one-meter width) with maximum cargo weight capacity of 15 to 18 tons. Most of the signaling systems and infrastructure were constructed since World War 2 and have been received only minor modernization (Ministry of Transport, 2006a). The North Line terminates at ampher Muang, Chiangmai province; the South Line terminates at ampher Su-ngai ko-lok, Narathiwat province; the Northeast Lines (North Isan) terminates at ampher Muang, Nong Khai province and the other line (South Isan) terminates at ampher Aranyaprathed, Sra-Kaew province; the East Line terminates at ampher Mabtaphud, Rayong province; and the West Line terminates at ampher Tsai-Ypok, Kanchanaburi province. The oldest locomotives in service were built in 1952 while the newest were built in 1995 (State Railway Authority of Thailand, 2010).

Although the tracks and stations are located near, if not next to, roads and highways, there are only a limited number of modal transfer points where cargo, especially container, handling equipment is available. The scarce transfer points with container handling capability are in the following provinces: Bangkok (Bangkok ports, Lad Krabang ICD), Chonburi (Laem Chabang port), Utaradit province, Khon Khaen province, Nakhorn Rajasima province, and Suratthani province (Ministry of Transport, 2006a).

In 2009, the railway authority of Thailand reported that 65% of cargos carried are containers, 24% are petroleum products, 10% are cement, and 1% for other goods. 90.5% of the total containers transported by rail are from Lad Krabang ICD to Laem Chabang port and vice versa.

Figure 3.4 Proportion of freight transport by rail in 2009



Source: The State Railway Thailand (2010a)

The railway connecting to Laem Chabang port and Lad Krabang ICD (see Appendix IV) was fully utilized and congested mainly because the railway is a single track. If rail is chosen to transport cargoes from Ayudhya to Laem Chabang port as the case study in this paper, the congested rail network between Lad Krabang to Laem Chabang can pose difficulty, uncertainty, or even an additional cost to the total transport cost. Consequently, rail transport in this route does not offer any benefit over inland waterway in terms of reliability or speed unless the bottleneck is solved. An expansion project of Laem Chabang railway to double tracks was approved by the Cabinets in 22 October 2007 (Manager, 2007; Krungthepthurakij, 2007).

However, rail freight transport in Thailand is unpopular among shippers and transport operators because of unreliability, poor service quality, and bureaucratic inefficiency of the State Railway of Thailand (Banomyong, 2004). Ministry of Transport (2006a) also reports that users usually complaint about delays of rail services, inadequate locomotives, and frequent derails. (The State Railway of Thailand is the monopoly rail transport operator and is state-owned. The SRT is responsible for both passenger and freight transport provision and an infrastructure owner as well. The SRT usually receives criticism of inefficiency, high political interference, and problematic labor union.)

3.2.4 Inland Waterway Freight Transport

Inland waterway freight transport in Thailand takes place in five major rivers of the country: Chao Praya, Pasak, Bang Pakong, Mae Klong, and Ta-Chin. The River Chao Praya is the biggest and the most important river of the country economically and historically. The river starts from Nakorn Sawan province in the central region of Thailand to Paknam Samut Prakarn connecting to the gulf of

Thailand. However, freight transport is possible only from Muang Angthong province to the gulf of Thailand because of draft restriction between Angthong and Nakorn Sawan province. The River Chao Praya gains its significance because it lies through economic and industrial areas such as Bangkok, Nonthaburi, Pathum Thani, Ayudhya, and Samut Prakarn linking these areas with two major internatnal ports: Bangkok port and Laem Chabang port. The river Pasak is another major river for inland waterway freight transport. The river connects to the River Chao Praya at Ayudhya province and lies through industrial estates within the province until it ends at Ampher Tarue in Ayudhya province. In 2007, the Marine Department reported that 53% of the total inland waterway freight transport is carried through the River Chaopraya, 30.1% through the River Pasak, 8.1% through the River Bang Pakong, 7.8% through the River Ta Chin, and only 0.1% through the River Mae Klong respectively (Ministry of Transport, 2006b).

A majority of the cargoes carried through the River Chao Praya and Pasak is bulk and break-bulk i.e. construction sand and rocks, cement, rice, sugar, cassava, coal, fuel, and fertilizer. For an import route, cargoes are discharged from ocean going vessels in Laem Chabang port, Bangkok port, or at Si Chang Island. The cargoes will then be loaded into barges which are towed by a small tow boat along the river until they reach destinations. Normally, inland waterway ports on the banks of River Chaopraya and Pasak are privately-owned dedicated ports serving specific requirements of the cargo owners. For an export route, cargoes will be transported from production facilities or warehouses, which are usually located near the river or in a close parameter, and loaded into the docking barges. The barges are towed to Bangkok port or Laem Chabang port where there are discharging/ loading facilities or to Si Chang Island where the cargoes will be handled by ship gears (At Si Chang Island, cargoes will be loaded or discharged alongside the ships). The nautical distance from Angthong to Pra Nakorn-sri-ayudhya is 38 kilometers, and 47 kilometers from Ampher Tarue. From Pra Nakorn-sri-ayudhya to Bangkok, the distance is 97 kilometers, 142 kilometers to the Chao praya delta on the gulf of Thailand, and 214 kilometers to Laem Chabang (Bureau of Agricultural Economic Research, 2010).

Traditionally, rice is transported in forms of bulk (grains) and break-bulk (50-kilogram bags). In 2009, an initiative was made to transport rice in a container from a factory in Ampher Nakorn Luang, Ayudhya province to Laem Chabang port via inland waterway. Although transporting rice in a container is not new, inland waterway transport of containers along the River Chao Praya and Pasak had been rarely, if not never, done before.

Seidenfus (1994) notices situations in inland waterway transport in Germany and suggests that congestion and bottlenecks in the highways and railway network present a positive effect to inland waterway transport since it gives shippers increased incentives to shift modes. Inland transport has a disadvantage of high transit time, but congestion and bottlenecks narrow this gap as well as reduce reliability of road and rail. In combination with lower unit cost, inland waterway is an interesting alternative mode. As discussed earlier, both road and rail networks from and to major deep sea ports in Thailand, Bangkok port and Laem Chabang port, are facing congestion and under capacity problems. Consequently, inland waterway can be a solution for Thailand’s freight transport problem in this route, which is allegedly the most important route because it links major hinterlands with the gates to the international market. Being able to solve the problem thus helps the country to gain competitive advantage in terms of logistics costs and efficiency, as well as presents a choice for sustainable and environmental friendly mode of transport.

3.3 The Case Study

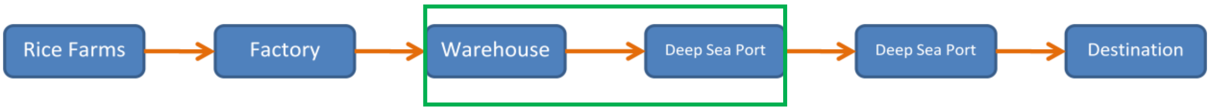
3.3.1 Overview of the Case Study

The supply chain of rice begins when rice is harvested at the farm. The grains are transported to a rice mill or a factory to polish and grade. At the factory, rice is grouped according to its grade and packaged in different sizes of bags. The most common sizes of packaging are 1-kilogram, 5-kilogram, 15-kilogram, 50-kilogram, and 1000-kilogram bags. For export rice, the rice is transported to a deep sea port by road, rail, or inland waterway. Rail is seldom used as a transport mode for rice because of inadequate handling equipment and transfer point between road and rail and inland waterway and rail. Road is the most common mode for rice in a container, and inland waterway is the most common mode for break bulk rice in bags (normally in 1000-kilograms bags). From the deep sea port the rice is loaded into an ocean-going vessel which will sail to a destination port. At the destination port the rice is discharged and shipped to a designated destination in the hinterland and to final customers at the end of the supply chain. The focus of this case study is the transport from the factory in Nakorn Luang, Ayudhaya province to the origin deep sea container terminal in Laem Chabang Port.

3.3.2 The Transport Processes

The scope of this thesis starts when the container is fully stuffed and ready to be hauled at the warehouse (Ex-work), and ends when the container reaches the container transfer point in Laem Chabang port. The figures used in the case and models are collected from costs of transport collected from companies' financial statements and balance sheets.

Figure 3.5 A Supply Chain of rice products



Source: The author

For a container of export rice, there are four possible alternatives in three modes to transport the cargo from the factory to the deep sea port.

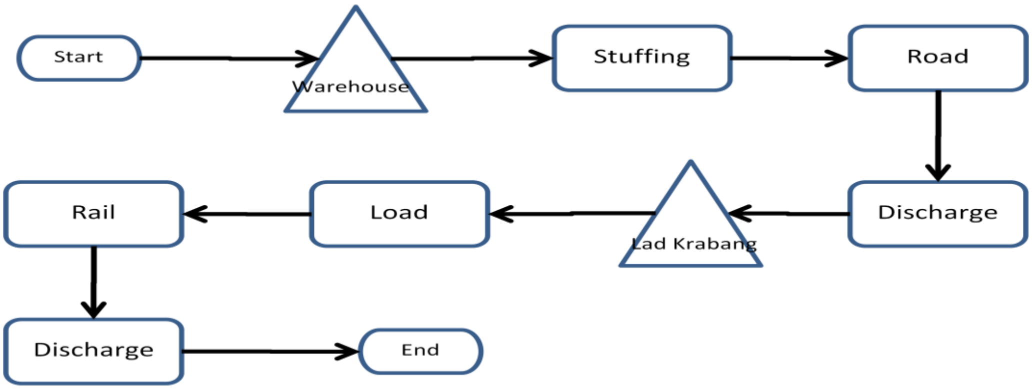
The first option is road transport. A truck hauls a container to the warehouse where the container will be stuffed with rice bags. After finishing the stuffing, the container is sealed and hauled to Laem Chabang deep sea port where the container will be lifted off the trailer and taken into port/carrier custody, waiting to be loaded into an ocean-going vessel.

Figure 3.6 Road transport of a container of rice products

Source: The author

The second alternative is a combination between road and rail. This multimodal option starts when the container is ready Ex-work. A road hauler transports the container from the warehouse/ factory in Ampher Nakornluang, Ayudhya province along highways to Lad Krabang inland container depot outside Bangkok. At the Lad Krabang ICD, the container is lifted off the truck and transfer to the container terminal in the ICD. When the container is scheduled to be transported to the ocean-going vessel, it will be load on a rail container wagon and carried by train from Lad Krabang ICD to Laem Chabang port where it will be discharged again and placed at the container yard inside the port.

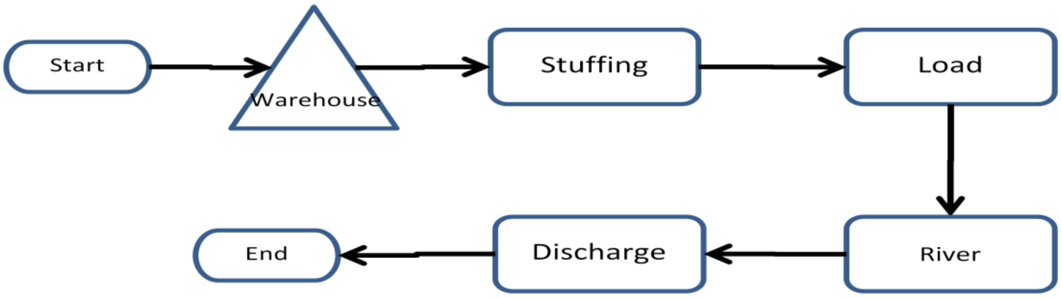
Figure 3.7 Multimodal transport (Road/Rail) of a container of rice products



Source: The author

The third option is transporting via inland waterway. After stuffing is completed, a truck or tractor hauls the container to a nearby river port. The container is then lifted off the trailer to the port and lifted again to load into a river barge. The river barge carries the container along the River Pasak, where the river port is located on, to the connecting River Chao Praya, exits the gulf of Thailand and continues to Laem Chabang deep sea port where the container will be discharged and placed in the container yard.

Figure 3.8 Inland waterway transport of a container of rice products



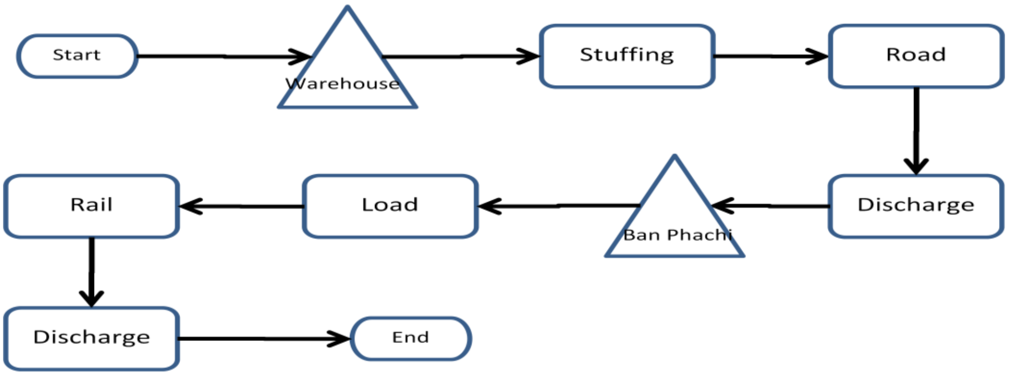
Source: The Author

The last option is rail transport, which is the least possible route at this moment because there is no equipment that is capable for container handling at the origin train station. Nevertheless, this option is also stated here only to complete the illustration of an intermodal competition. But because of absence of such service in reality, the cost data and figures for this route is derived from estimations and assumptions which will be discussed further when this route is explored later.

The container will be transported from the warehouse to Ban Phachi railway station in Ayudhya province, then lifted off the trailer and lifted on to a rail wagon. The train will runs from Ban Phachi station on the East route and stops at Laem Chabang port, where the container will be lifted off and send to the container yard.

Ban Pha Chi railway station is currently able to accommodate only passenger transport. But because the station is also a shaunting yard, thus this is the closest potential station for freight transport in this case.

Figure 3.9 Rail transport (Ban Phachi) of a container of rice products



Source: The author

Cost models and cost curves of the four possible routes will be constructed and analyzed as the next section is reached. However, the analysis in this Chapter is based primarily only on the first three choices: all-road, road and rail (Lad Krabang), and inland waterway since the last option has a little possibility and impractical at this moment.

3.4 Indicating Transport Costs from the Case Study

3.4.1 Road transport (Nakorn Luang – Road Transport – Laem Chabang Port)

This cost calculation is based on the following assumptions: Price of a trailer truck is THB 4,000,000, price of a container trailer (2 axes, 2 TEU) is THB 1,500,000, economic life of a trailer truck is 5 years, economic life of a container trailer is 5 years, assumed number of TEU per haul is 1.6 TEU (80% utilization), all hauls are assumed to be laden, average fuel price is THB 30 per liter, consumption rate is based on a study by Ministry of transport (2006a) at 0.7 liter per kilometer, average distance is based on a study by Ministry of transport (2006a) at 7,800 kilometers per month, and average speed is 50 kilometers per hour (ministry of transport, 2006a).

Inputs required by the model can be found in a financial statement of the company. When rearrange the accounting items according to the model's requirements (namely from Equation 3.1 and 3.2), the cost items of a truck and a trailer can be presented as:

Table 3.2 Total Transport Cost per Twenty-foot Equivalent Unit per Kilometer of road transport

Capital costs p.a.	
DP	1,100,000
Interest	45,000
Total CC	1,145,000
Operating Costs p.a.	
Labor	240,000
MA	160,000
Fuel	1,965,600
Traffic	65,520
Taxes	10,000
Insurance	13,700
Overhead	40,000
Misc	4,000
Total OC	2,498,820
TTC p.a.	3,643,820
km travelled p.a.	93,600
TTC/km	39
TEU/haul	1.6
ATC teukm	24.33

Source: The author

The depreciation is calculated using straight-line method with an economic life of 5 years, thus the annual depreciation is $\frac{4,000,000}{5}$ = 800,000 for a trailer truck and $\frac{1,500,000}{5}$ = 300,000 for a container trailer. The average compensation for a truck driver is THB 20,000 per month or 240,000

Fuel consumption is estimated at 0.7 liter per kilometers (ministry of transport, 2006a), and total distance travelled per annum is 7,800*12 = 93,600. Consequently, fuel cost per annum at an average fuel price of THB 30 is 0.7*93,600*30 = 1,965,600

Total transport cost (TTC) per annum is = total capital costs (CC) + total operating costs (OC) = 1,145,000 + 2,498,820 = 3,643,820

The total transport cost per kilometer is derived from dividing the total transport cost (TTC) per annum by total distance travelled per annum or 3,643,820/93,600 = 39

With 80% utilization, an average number of TEU carried per haul is 1.6, hence, total transport cost per TEU per kilometer is $\frac{39}{1.6}$ = 24.33

Details of this transport option can be found in the following table. The cargo is transported via road from the origin to the destination. The total transit time is approximately 4 hours with 200 kilometer distance. The average transport cost is THB 24.33 per kilometer; hence, the total transport cost of 1 TEU per haul is THB 4,866

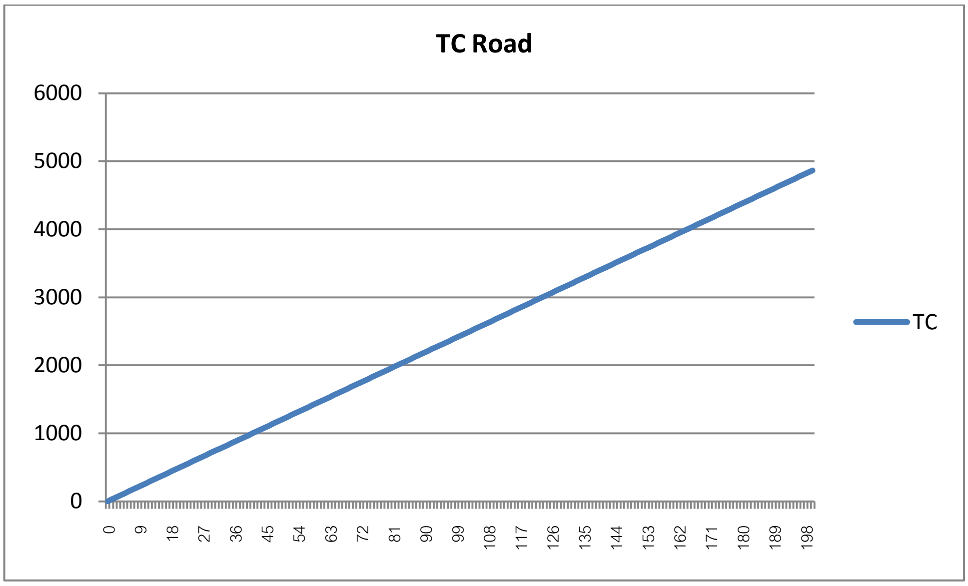
Table 3.3 Road transport route Nakorn Luang – Laem Chabang Port

Leg	Mode	Transit time (Hour)	Distance (KM)	Cost (THB)	Total Cost (THB)	Accumulated Total Cost (THB)
Nakorn Luang Warehouse - Laem Chabang Port	Road	4	200	24.33/km	4866	4866
Total		4	200		4866	

Source: The author

From the data above, a graph representing transport cost of this option can be shown as in figure 3.10

Figure 3.10 Cost model of route Nakorn Luang – Laem Chabang Port



Source: The author

3.4.2: Road/Rail Transport (Nakorn Luang – Lad Krabang Inland Container Depot – Laem Chabang Port)

The second option involves two modes of transport: road and rail. The container is transported from the warehouse in Nakorn Luang by truck, then unloaded at Lad Krabang Inland Container Terminal outside Bangkok. From Lad Krabang ICD, the container is transported to Laem Chabang Port by train operated by the State Railway of Thailand (the State Railway of Thailand holds a monopoly position in rail transport services in Thailand).

Assumptions for transport leg by truck are identical with the assumptions in the first option (all roads). However, because of limitation in availability of data on operational costs of the State Railway of Thailand (which will be discussed further when the rail mode is reached), the average total transport cost will be based on the cost of freight service mentioned on the State Railway of Thailand's website (SRT, 2010) at THB 8 per kilometer.

Table 3.4 Rail transport route Nakorn Luang – Lad Krabang Inland Container Depot – Laem Chabang Port

Leg	Mode	Transit time (Hour)	Distance (KM)	Cost (THB)	Total Cost (THB)	Accumulated Total Cost (THB)
Nakorn Luang Warehouse - Lad Krabang ICD	Road	3	100	24.33/km	2433	2433
Lad Krabang ICD: Handling charge		12	0	550	550	2983
Lad Krabang ICD - Laem Chabang Port	Rail	3.5	94	8/km	752	3735
Laem Chabang Port: Train transfer charge		4	0	450	450	4185
Total		22.5	194		4185	

Source: The author

The cost of transporting a one-TEU container from the warehouse in Nakorn Luang to Lad Krabang ICD via road is adopted from the average total transport cost per TEU per kilometer in the first route, which is THB 24.33

The distance of road transport from Nakron Luang to Ladkrabang ICD is 100 kilometers; therefore, the transport cost for road haulage is 24.33*100 = THB 2,433 and the transit time for this leg is approximately 3 hours (because of regular traffic jams in Bangkok's suburb areas where the ICD is located on).

At Lad Krabang ICD, the charge that the ICD collected from users as handling charge is THB 550 per TEU. There are 12 trains per day connecting the ICD to Laem Chabang Port. At the ICD, the container will be placed in a container yard in the ICD, waiting for the specified train, and then loaded on a freight wagon which will carry the container to Laem Chabang Port. According to RAT (2010), one train can haul up to 20 units of 2-TEU wagon with average speed of 30 kilometer per hour (Minister of Transport, 2006).

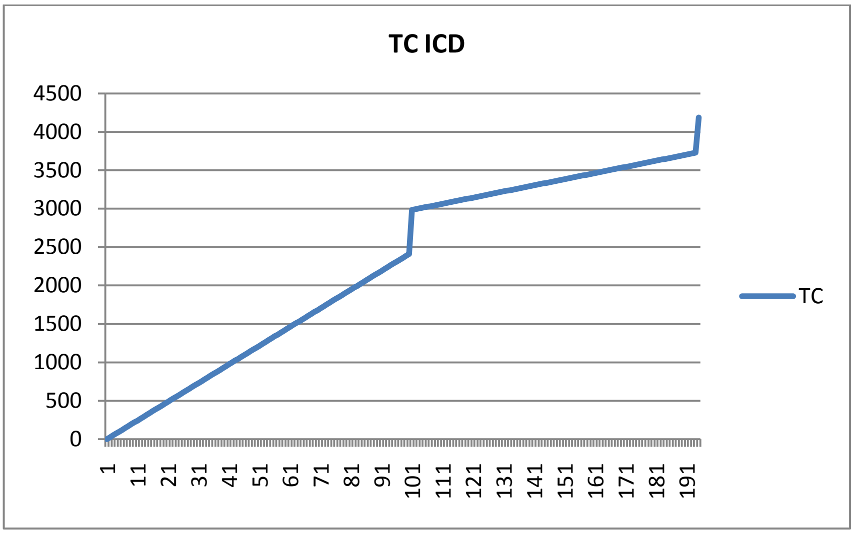
From Lad Krabang ICD, the container is transported by a train to Laem Chabang Port for 94 kilometers. The normal transit time in this leg is 3.5 hour. With the average transport cost of THB 8 per kilometer, this leg has a cost of 8*94 = THB 752

At Laem Chabang Port, a charge of THB 450 per TEU is imposed by the port as train transfer charge before the container reaches the container yard inside Laem

Chabang Port. In total, overall transit time for this leg is around 22.5 hours, total distance is 194 kilometer, and total transport cost from the warehouse to Laem Chabang port is THB 4,185

With this cost data, a graph can be constructed as in the figure 3.11 below

Figure 3.11 Cost model of route Nakorn Luang – Lad Krabang Inland Container Depot – Laem Chabang Port



Source: The author

3.4.3 Inland waterway transport (Nakorn Luang – Pasak River – Chao Praya River – Laem Chabang Port)

In this option, the container is hauled from the factory to Nakorn Luang river port nearby and loaded in a container barge. The barge sails from Nakorn Luang through River Pasak, and River Chaopraya. After exiting the gulf of Thailand, the barge will call Laem Chabang Port at A4 terminal which is capable for barge and coastal shipping handling. The container will be discharged from the barge and transported to a predetermined international terminal inside Laem Chabang Port.

Assumptions for the cost calculation in this route are: Price of a container barge (self-propelled) is THB 60,000,000, economic life of a container barge is 12 years, assumed number of TEU per voyage is 48 TEU (80% utilization of 60-TEU capacity), all containers are assumed to be laden, average fuel price is THB 30 per liter, consumption rate is based on a study by Ministry of transport (2006a) at 0.5 liter per kilometer, number of sailing per week is 1, and navigation distance from Nakorn Luang to Laem Chabang port is 250 kilometers. Inputs variable for the model can be illustrated as follows:

Table 3.5 Total Transport Cost per Twenty-foot Equivalent Unit per Kilometer of inland waterway transport

Capital costs p.a.	
DP	5,000,000
Interest	30,000
Total CC	5,030,000
Operating Costs p.a.	
Labor	720,000
MA	560,000
Fuel	452,400
Traffic	-
Taxes	25,000
Insurance	1,100,000
Overhead	566,552
Misc	360,000
Total OC	3,783,952
TTC p.a.	8,813,952
km travelled p.a.	26,000
TTC/km	339
TEU/haul	48
ATC teukm	7.06

Source: The author

Depreciation is calculated from dividing barge building cost by economic life or $\frac{60,000,000}{12}$ = 5,000,000 per annum. Labor cost is obtained from the fact that a container barge requires 6 crews on board: 1 captain, 1 first mate, 1 first engineer, and 3 sailors. Average monthly compensation for a barge captain is THB 20,000; 15,000 for a first mate and a first engineer; and 10,000 for a sailor. Consequently, total annual labor cost for a barge is 20,000 + (2*15,000) + (3*10,000) = 720,000

Maintenance and repair costs are estimated based on the previous year (2009) expenses. The fuel cost is based on an average fuel (diesel gasoline) price of THB 30 per liter. A voyage from Nakorn Luang to Laem Chabang port is 250-kilometer long with sailing frequency of once a week (return), thus, total sailing distance per annum is distance of the voyage*return trips*number of week per annum or 250*2*52 = 26,000 kilometers. With a consumption rate of 0.5 liter per kilometer, the total fuel cost per annum is consumption rate*sailing distance per annum*average fuel price or 0.5*26,000*30 = 452,400

Taxes, insurance premiums, overhead, and miscellaneous expenses are based on expenses of the previous year. The costs are allocated in the same proportion for every barge in the fleet notwithstanding the real cost occurrences because the financial data is recorded in a high level of aggregation. For instance, the insurance cost for a barge is derived from dividing total insurance expenses by the number of barges in the fleet or $\frac{4,400,000}{4}$ = 1,100,000

Total transport cost (TTC) per annum is = total capital costs (CC) + total operating costs (OC) = 5,030,000 + 3,783,952 = 8,813,952. The total transport cost per kilometer is derived from dividing the total transport cost (TTC) per annum by total distance travelled per annum or $\frac{8,813,952}{26,000}$ = 339. With 80% utilization, an average number of TEU carried per haul is TEU capacity of the barge*0.8 or 60*0.8 = 48, hence, average transport cost per TEU per kilometer is $\frac{339}{48}$ = 7.06

Table 3.6 Inland Waterway transport route Nakorn Luang – River Pasak – River Chaopraya – Laem Chabang Port

Leg	Mode	Transit time (Hour)	Distance (KM)	Cost (THB)	Total Cost (THB)	Accumulated Total Cost (THB)
Nakorn Luang Warehouse - Nakorn Luang River Port	Road	0.5	1	24.33/km	24.33	24.33
Nakorn Luang River Port: Handling charge		12	0	300/lift	600	624.33
Nakorn Luang - Laem Chabang (A4)	River	29	250	7.06/km	1765	2384.33
Laem Chabang Port: Barge transfer charge		3	0	560	560	2949.33
Total		44.5	251		2949.33	

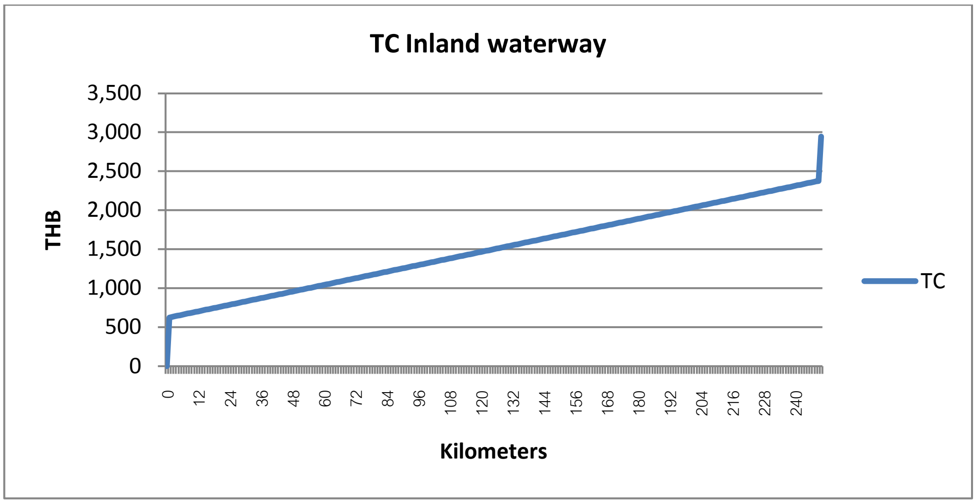
Source: The author

At Nakorn Luang port, the cost per lift according to financial statements of the port operator is THB 300/lift. The mode transfer at this node requires 2 lifts: from trailer to port and from port to barge. Therefore, the total handling cost at Nakorn Luang port is 300*2 = THB 600

The cost of river transport is THB 7.04 per kilometer, thus, the total cost of the leg from Nakorn Luang to Laem Chabang is 7.04*250 = THB 1,760

Laem Chabang also imposes a charge of THB 560 per TEU for barge transfer (discharging the container from the barge to the port). In summary, the total transport cost of this inland waterway mode is THB 2,944.33; total transit time is approximately 44.5 hours; and total distance is 251 kilometers.

Figure 3.12 Cost model of route Nakorn Luang – River Pasak – River Chaopraya – Laem Chabang Port



Source: The author

3.4.4 Rail Transport (Nakorn Luang – Ban Phachi Train Station – Laem Chabang Port)

Although this option does not exist currently in reality because there is no transfer point between road and rail available in the 100-kilometer radius of the warehouse, the option is still presented here to complete the picture of competition between every transport mode. Ban Phachi station is capable of handling passenger transport at this moment, but not freight. However, this station is the most potential candidate for development to facilitate freight transport because it is a haunting yard and located on a main railway which freight trains already run through.

Unfortunately, because the State Railway of Thailand does not present financial statements of its freight services but consolidates the activity together with passenger operations (State Railway of Thailand, 2007). As a result, the inputs required for the model cannot be identified properly. Nonetheless, the State Railway of Thailand implies on its website that an average cost for rail freight transport is approximately THB 8 per kilometer (State Railway of Thailand, 2010)

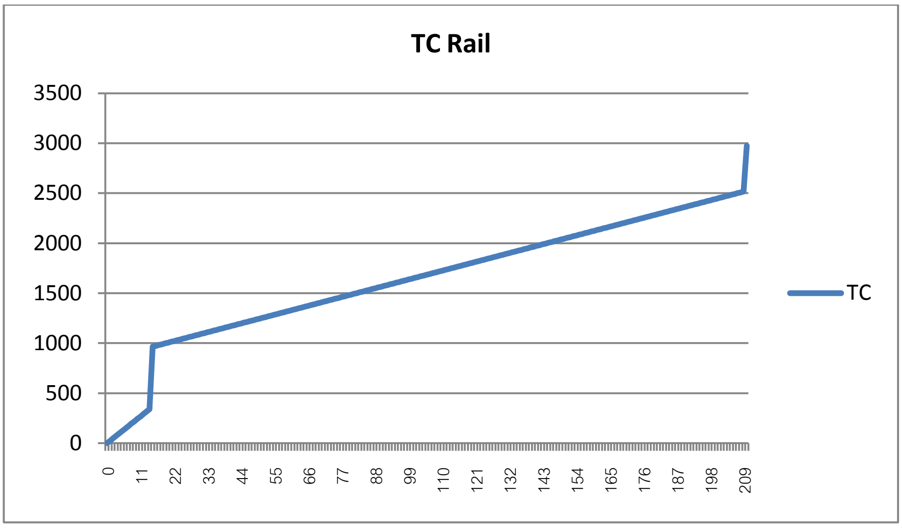
Table 3.7 Rail transport route Nakorn Luang – Ban Phachi – Laem Chabang Port

Leg	Mode	Transit time (Hour)	Distance (KM)	Cost (THB)	Total Cost (THB)	Accumulated Total Cost (THB)
Nakorn Luang Warehouse - Ban Phachi Train Station	Road	1	15	24.33/km	364.95	364.95
Ban Phachi Station: Handling charge		12	0	550	550	914.95
Ban Phachi - Laem Chabang Port	Rail	6.5	195	8/km	1560	2474.95
Laem Chabang Port: Rail transfer charge		4	0	450	450	2924.95
Total		23.5	210		2924.95	

Source: The author

Ban Phachi station is located 15 kilometers east of the warehouse, which means the container must be transported there by a truck. The 15-kilometer leg from the warehouse to the train station costs 15*24.33 = 364.95 (the average cost of THB 24.33 per kilometer of road transport is obtained from the calculations in the all-road option in route 1). The handling cost at Ban Phachi station is assumed to be equal to that of Lad Krabang Inland Container Depot at THB 550 because it is also a transfer from road to rail. The leg from Ban Phachi station to Laem Chabang port is 195 kilometers long. With the rail transport cost of THB 8 per kilometer, the total transport cost of this leg is 8*195 = THB 1,560. The transfer time at Ban Phachi is quite long (12 hours) because normal frequency of the north line freight train is 2 per day; hence, some slack time should be incorporated in the calculation. Finally, at Laem Chabang port, the port collects THB 450 per TEU as a rail transfer charge. The total transport cost of this rail option is THB 2975 with 24-hour transit time and 210 kilometers travelled.

Figure 3.13 Cost model of route Nakorn Luang – Ban Phachi – Laem Chabang Port



Source: The author

3.5 Analysis

Table 3.8 Transport cost comparisons in percentage

Mode	Road	Rail	Inland waterway	Road/Rail
Road	-	64%	65%	16%
Rail	-39%	-	1%	-29%
Inland waterway	-39%	-1%	-	-30%
Road/Rail	-14%	41%	42%	-

Source: The author

Road transport has the highest cost. The cost of freight transport via roads is 64% higher than rail (the figure is derived from (transport cost of road – transport cost of rail)/ transport cost of rail or (4,866 – 2,975)/2,975 = 0.64 or 64%), 65% higher than inland waterway, and 16% higher than road and rail. On the other hands, the cost of transporting a twenty-foot container for 250 kilometers via inland waterway (barge) is 39% less than transporting via road, 1% less than rail, and 30% less than the current available multimodal transport option. The transport cost of multimodal transport is quite high because the distance via rail, which has lower average transport cost per kilometer, is very limited to only 94 kilometers.

Table 3.9 Transport costs of different modes in Thailand

Mode	Average Transport Cost per km (THB)
Road	24.33
Rail	8.00
Inland waterway	7.06

Source: The author

Road transport is also the most expensive in terms of average transport cost per kilometer. With the average transport cost of THB 24.33 per kilometer, road transport costs 204% more than the cost of transporting via rail and inland waterway. In other words, rail and inland waterway is 67% and 71% cheaper than road accordingly. But because of absence of additional costs at transfer nodes and extra transport to the transfer nodes, road transport has lower total cost for transport in a short distance.

Among three transport modes, inland waterway provides the least total transport cost of THB 2,944, followed by rail at THB 2,975, and road has the highest transport cost of THB 4,866. However, despite the lowest cost provision, inland waterway presents the longest transit time and distance. The long transit time imposes a significant disadvantage on inland waterway transport especially with time-sensitive cargoes such as perishables, high value cargoes, and short product life cycle items. Road transport, on the other hands, has the shortest transit time. This is largely because of flexibility of the road transport, greater speed, and absence of mode transfer. The flexibility represents in the form that a truck is able to access to any premises and road network easily compared to rail and inland waterway where there has to be rail or waterway for the transport to be plausible. The higher average speed of road transport of 60 kilometers per hour is superior to 30 kilometers per hour for rail and 8 kilometers per hour for inland waterway (Ministry of Transport, 2006a).

A combination of Road and Rail also illustrates that multimodal transport can reap a benefit of each mode and provides a lower total transport cost. However, the total transit time is quite long because of a significant amount of time is spent at the modal transfer point, especially at Lad Krabang ICD. This is caused by current over capacity of the ICD and the railway connecting the ICD to Laem Chabang Port. The ICD is designed to accommodate only 1 million TEU per annum (State Railway of Thailandb, 2010) while the actual throughput is overwhelming, and the railway is still a single track. Although expansion projects for both ICD and track have been carried out, the current effective supply already lags behind the demand and the congestion at the ICD and railway causes time waste to the transport chain.

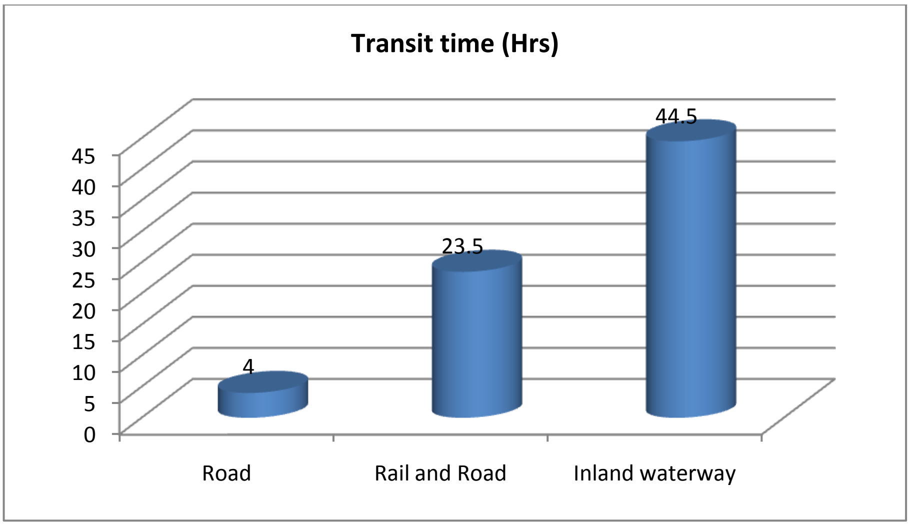
Table 3.10 Summary of transit time, distance and costs of each mode

Mode	Transit time (Hrs)	Distance (km)	Total Transport Cost (THB)
Road	4	200	4866
Rail	23.5	210	2925
Inland waterway	44.5	251	2949
Road/Rail	22.5	194	4185

Source: The author

Road is the fastest transport option with transit time of only 4 hours, followed by rail/road at 23.5 hours, and Inland waterway is the slowest mode with 44.5-hour transit time. The advantages of road transport are flexibility, accessibility, and short transit time. Flexibility means the container can be sent to the destinations, in this case is Laem Chabang Port, with higher frequency because trailer trucks do not have to wait for container consolidation and aggregation. Relatively, road transport is 83% faster than rail (this figure is calculated from (transit time of road – transit time of rail)/transit time of rail = (4-23.5)/23.5 = -83%), 89% faster than inland waterway, and 76% faster than multimodal of road and rail. On contrary, inland waterway has the longest transit time. Transit time of inland waterway in this case is 7.8 times longer than road, 0.51 times longer than rail, and 1.15 times longer than multimodal transport of road and rail. The most expensive transport mode is also the fastest, while the cheapest mode is the slowest. It is clear that, there is a trade-off between speed and transport cost in this case.

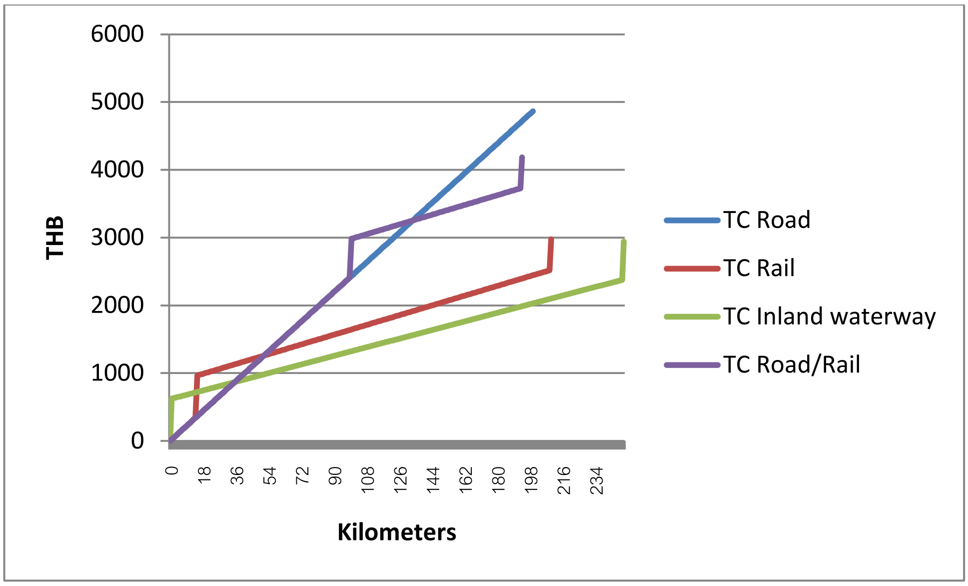
Figure 3.14 Transit time comparisons of different transport options



Source: The author

When a cost curve of each mode is constructed and compared, it is obvious that road transport cost curve has the highest slope because of more expensive cost per kilometer. Rail and inland waterway have substantial lower cost per kilometer than road but require longer transit time. The figure shows that rail transport is an interesting option because it has much lower cost than road but faster transit time than inland waterway. Unfortunately, the rail option for this case does not currently exist and the freight transport via rail represents only a small fraction in total freight transport in Thailand (Ministry of Transport, 2006b).

Figure 3.15 Summary of transport cost models of each mode



Source: The author

Another observation is that rail and inland waterway in this case have only slightly difference in average transport cost per kilometer. This raises an interesting idea for infrastructure and investment. Since rail transport is more accessible compared to inland waterway because railways can be constructed more easily than a waterway, rail transport should receive significant attention from policy makers in order to promote more economical option for freight transport.

In this chapter, the transport costs of each mode are obtained. In case of Thailand, the average transport cost by road is THB 24.33 per one twenty-foot Equivalent unit (TEU) per kilometer. The average transport cost of one TEU by rail is THB 8 per kilometer and THB 7.06 per kilometer by inland waterway. These cost figures will be adopted to develop a model in the next chapter.

3.6 Chapter Conclusion

Instead of using freight rates or prices of transport services as found in the literature, the model in this Chapter adopts actual transport costs of each mode and quantifies total and average transport cost per kilometer. Factors such as Average Transport Cost per Kilometer (ATC_{KM}), Total Transport Cost per unit-haul (TTC_{UH}) are redefined in order to indicate Average Transport Cost per TEU per Kilometer (ATC_{TEUKM}), and Total Transport Cost per TEU (TTC_{TEU}). Values of TTC_{TEU} can be found by solving equation ATC_{TEUKM}, and TC_{MT} and ATC_{TEUKM} is derived from solving equation ATC_{KM}. The equation TTC_{TEU} is a modification of equation TTC_{UH} (Total Transport Cost per unit haul where the unit is TEU. Equations TTC_{UH} and ATC_{UKM}

(Average Transport Cost per unit haul) are more general than TTC_{TEU} and ATC_{TEUKM} because the unit measurement can be altered to TEU, FEU (Forty-foot equivalent unit), Bags, or Kilograms by changing the dividing factor (N_U) to number of TEU (N_{TEU}) or number of FEU (N_{FEU}) or Number of bags (N_{BAGS}) or Kilograms (KGS).

The result of the model with actual transport costs follows the same trend with the model with prices. The actual costs are adopted in this model because costs are not as much influenced by other factors than operations as prices. The average transport cost per kilometer per one twenty-foot Equivalent unit (TEU) in case of Thailand of each mode is identified in this chapter. Road has average transport cost per TEU per kilometer (ATC_{TEUKM} road) of THB 24.33, rail has average transport cost per TEU per kilometer (ATC_{TEUKM} rail) of THB 8, and inland waterway has average transport cost per TEU per kilometer (ATC_{TEUKM} inland waterway) of THB 7.06. Road transport does not require any modal transfer; therefore, there is no handling cost occurs. Rail and inland waterway transports, on the other hands, generate costs of transferring the transport mode such as cargo handling operations which creates additional costs. The modal transfer costs of rail are THB 1,000 in total (THB 550 at the loading node and THB 450 at the discharging node). The modal transfer costs of inland waterway are slightly higher than that of rail mainly because of larger depreciation and investment on infrastructure. The modal transfer costs of inland waterway are THB 600 at the loading node (the river port in Nakorn Luang) and THB 560 at the discharging port (Laem Chabang). By modeling the transport cost traditionally, two types of costs can be identified according to their different characteristics: variable and fixed costs. Variable cost in this sense is the cost that varies by number of kilometers and fixed costs are the costs that occur notwithstanding the distance travelled. The variable cost is the average transport cost per TEU per kilometer, while fixed costs are costs of modal transfers such as handling costs, shuttle transport, and other charges.

Chapter 4 Modeling Intermodal Competition of Freight Transport in Thailand

4.1 Developing the model

The new model will use actual transport cost of each mode rather than freight rates or prices. The reason why the actual transport cost is more appropriate is that freight rates are influenced by several factors other than costs such as market condition and competition level. In order to develop a model assisting precise decision making on public policy, other factors than transport cost must be limited. The model is aimed to provide an answer to a question what the optimal distance for transport mode shifts is. To obtain the answer, the transport cost curve of each mode has to be formulated in a linear form. This can be done by modifying the equation 3.9

$$TTCteu = (ATCukm \times KMt) + TCmt \tag{3.9}$$

The equation 3.9 can be written in a linear equation form by setting distance in kilometer as an independent variable (X variable), the total transport cost per Twenty-foot Equivalent unit (TEU) per haul as a dependant variable (Y variable), and the total handling costs per TEU per haul as a constant. Thus, the modified equation is

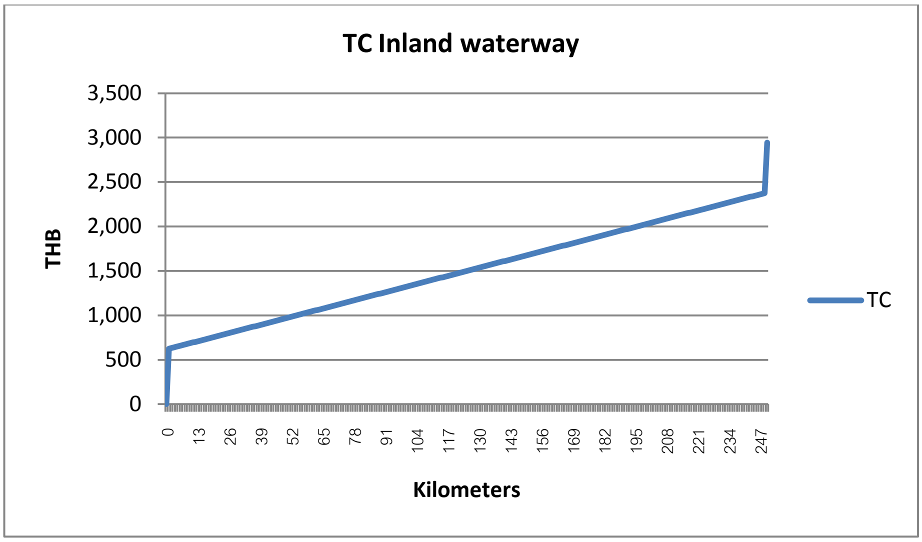
$$TTCteu = (ATCteukm \times X) + TCmt \tag{4.1}$$

TTC_{TEU}	=	Total Transport Cost per TEU
ATC_{TEUKM}	=	Average Transport Cost per TEU per kilometers
X	=	Distance in kilometers
TC_{MT}	=	Total Costs of Modal Transfer

The total cost of modal transfer is a summation of costs of modal transfer at each node in the transport. Examples of costs of modal transfer are handling charges at transfer nodes (i.e. loading, discharging, transit), gate charges, transfer fees, etc.

From the case study, it can be seen that the costs of modal transfer occur at the different number of kilometers. However, to construct a model with linear cost line, the costs of all modal transfers must be assumed to occur at the zero kilometer.

Figure 4.1 Traditional cost model of inland waterway transport



Source: The author

To illustrate clarify of the concept; figure 4.1 shows a traditional cost model of inland waterway. At the first kilometer, the total transport cost is THB 624.33 which comprises of cost of road haulage for THB 24.33 and handling cost at the port of THB 600. From the second to two hundred fiftieth kilometer, total transport cost is equal to average transport cost of inland waterway * number of kilometer or 7.06 * 250 = THB 1,760. Finally, at the destination of this haul (Laem Chabang Port), there is a cost of THB 560 for barge transfer charge imposed by the port. The total cost of inland waterway transport in this case is = 624.33 + 1,760 + 560 = 2,949.33

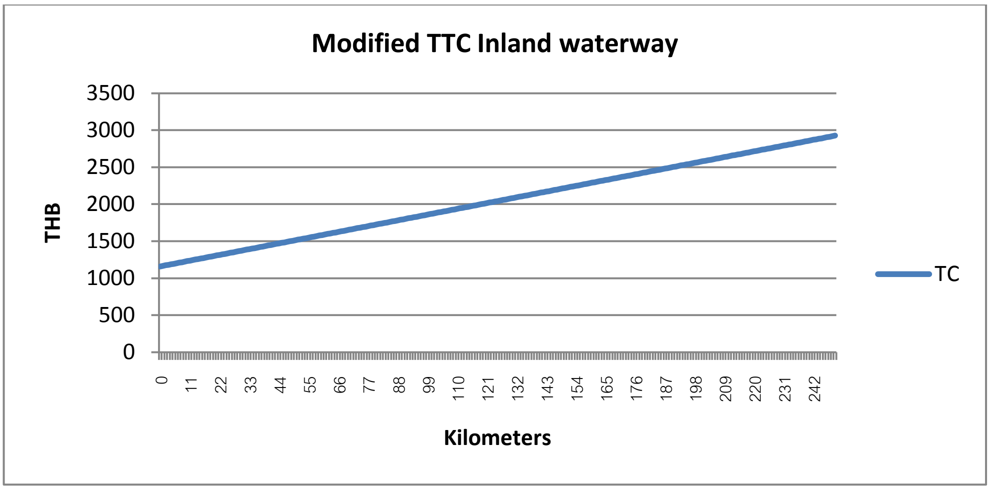
The modified model assumes that all costs of modal transfer occur at the zero kilometer, which includes the handling cost at the loading port of THB 600, and the transfer charge at the discharge port of THB 560. Although inland waterway needs road transport to bridge between the premise and the transfer node, the road haulage is neglected at this point because the initial model assumes that there is no bridging transport required. As a result, the total cost of modal transfer is = 600 + 560 = THB 1,160

With average transport cost of inland waterway at THB 7.06 per kilometer, a linear equation of inland waterway transport can be constructed as:

$$TTC\ inland\ waterway = 7.06X + 1{,}160$$

In the case study in the chapter 3, the total distance of inland waterway transport is 250 kilometers. Consequently, using the linear equation, the total transport cost of inland waterway per TEU is 1,160 + 7.06*(250) = THB 2,925 which is identical to the total cost value obtained from the traditional cost model method excluding the cost of road haulage (2,949.33 – 24.33 = 2,925).

Figure 4.2 Modified model of inland waterway transport



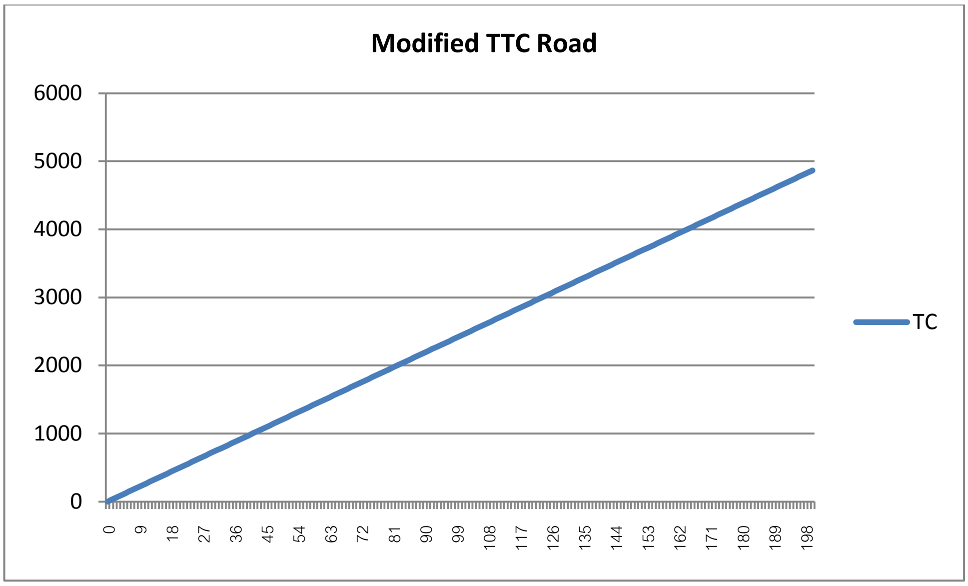
Source: The author

The transport cost equation of road can be constructed in the same way. Since road transport usually does not require any modal transfer, the total cost of modal transfer is none. Road has the average cost per kilometer is THB 24.33, as a result, the cost equation of road transport can be identified as

$$TTC\ road = 24.33X$$

Thus, with total distance of 200 kilometers as in the chapter 3 case study, the total transport cost of road per TEU is 24.33*200 = THB 4,866

Figure 4.3 Modified model of road transport



Source: The author

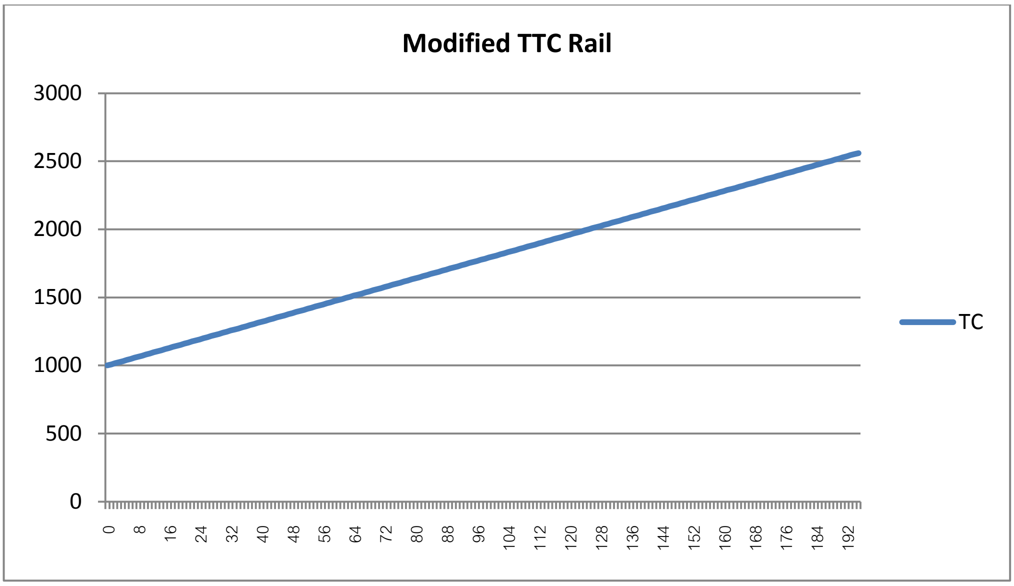
Rail transport also requires two modal transfers at the loading station and at the discharging station. The costs of modal transfers according to the case study are THB 550 and THB 450 respectively. The case study in the chapter 3 also reveals that the average transport cost of rail is THB 8 per kilometer. With the same assumption as inland waterway transport, the model assumes that road transport to bridge between the origin and the transfer node is not required. Hence, the total cost of modal transfer in this case is 550 + 450 = THB 1,000

The cost equation of rail transport is thus

$$TTC\ rail = 8X + 1{,}000$$

In the chapter 3.2 case study, the total distance of rail transport is 195 kilometers. Consequently, using the linear equation, the total transport cost of rail per TEU is 1,000 + 8 *(195) = THB 2,560. The cost is identical to the total cost value obtained from the traditional cost model method excluding the cost of road haulage (2,925 – 364.95 = 2,560). This confirms the validity of the equation and the modified model.

Figure 4.4 Modified model of rail transport



Source: The author

At this point, this paper is able to identify a cost equation of each transport mode in case of Thailand. The equations are

$$TTC\ road = 24.33X$$

$$TTC\ rail = 8X + 1{,}000$$

$$TTC\ inland\ waterway = 7.06X + 1{,}160$$

Subject to the following assumptions: Returns to scale are constant, the calculation is based on an average fuel (diesel) price of THB 30 per liter, utilization rate of vehicles is 80%, and other case-specific assumptions in calculations of each transport mode as stated in the chapter 3.

With the linear cost equation of each transport mode, an intersection of each mode can be found by using a mathematical technique. An intersection of the TTC inland waterway (Y1) and TTC road is

$$X = 67.1685$$

An intersection of road and 3 is

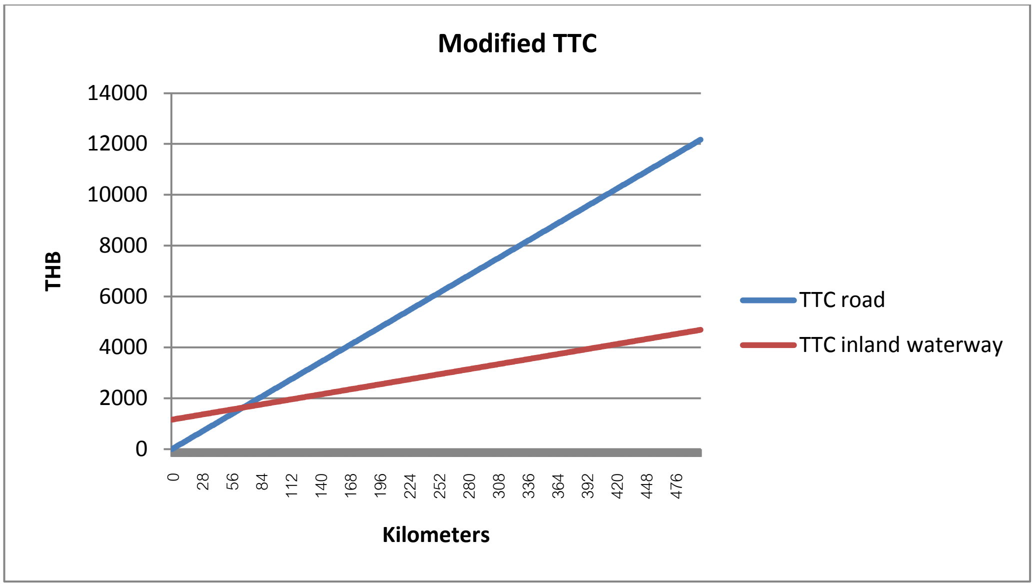
$$X = 61.237$$

An intersection of inland waterway and rail is

$$X = 170.2128$$

The outcomes suggest that an intersection of road and inland waterway is at 67.17 kilometers. An intersection of road and rail is at 61.24 kilometers. And an intersection of inland waterway and rail is at 170.21 kilometers. When use the equations to construct a cost line of each transport mode with distance of 500 kilometers, the outcomes is as shown in the following figures:

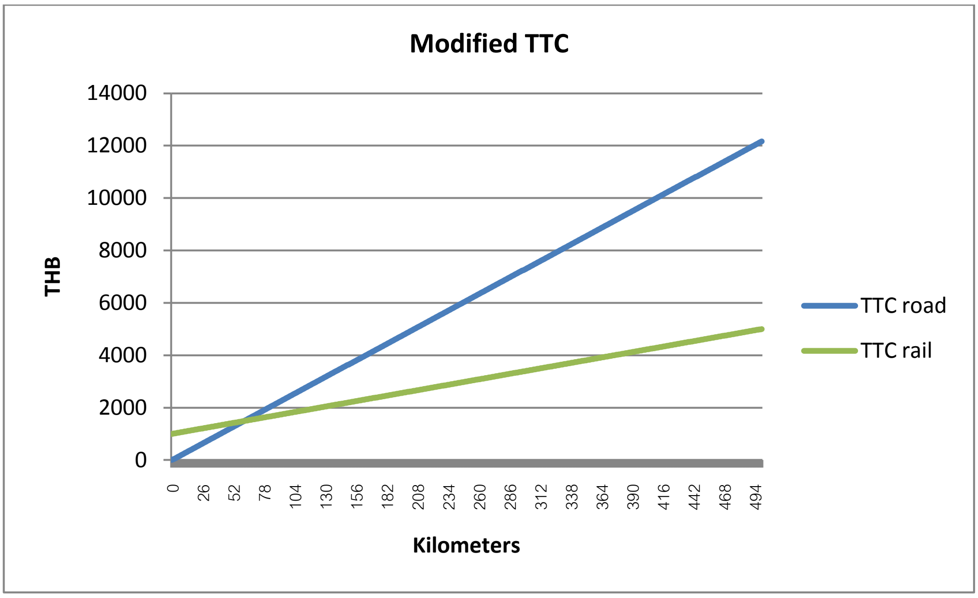
Figure 4.5 Modified models of road and inland waterway transport



Source: The author

At zero kilometer, road transport has lower cost than inland waterway because road does not require any modal transfer which creates cost. The intersection between cost lines of road and inland waterway at X = 67.17 is a break-even point of road and inland waterway transport. The break-even point suggests that the cost of road transport from the zero kilometer to the 67.17 kilometers is lower than the cost of inland waterway transport. At the 67.17 kilometers, the costs of road transport and inland waterway, which already includes modal transfer costs, are equal. And from the 67.17 kilometers, the cost of road transport exceeds the cost of inland waterway. An interpretation can be made that it is more economical to transport a cargo (a box of one twenty-foot container in this case) by road for a distance of lower than 67.17 kilometers. And from the 67.17 kilometers, it is more economical to transport the cargo via inland waterway. This means if a cargo is destined at a distance lower than 67 kilometers, the most economical mode of transport is road. But if the destination of the cargo is more than 67 kilometers away, inland waterway becomes the most economical mode.

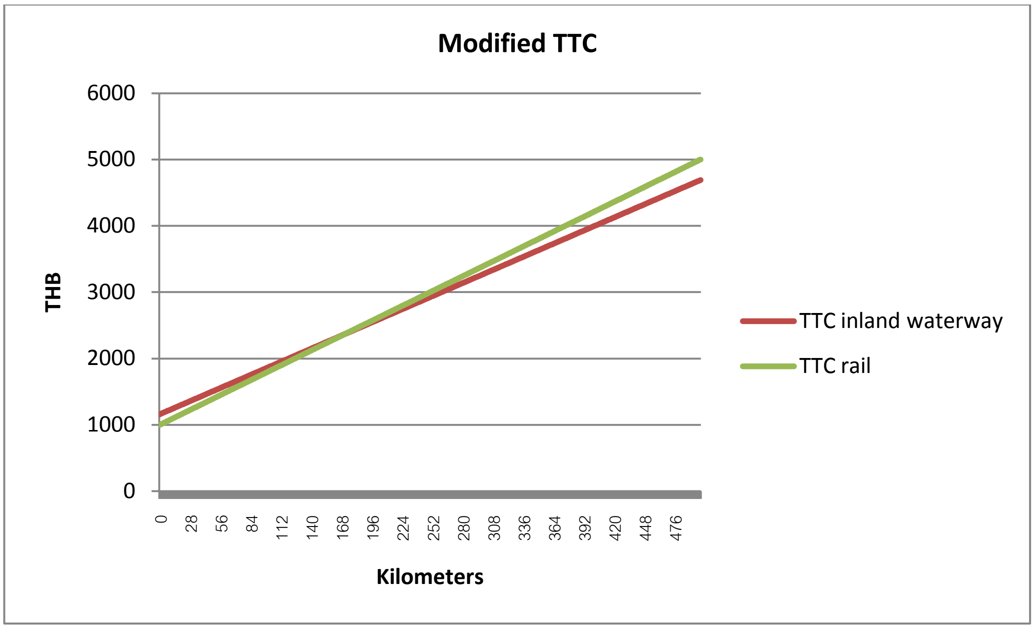
Figure 4.6 Modified models of road and rail transport



Source: The author

The intersection of road and rail transport is at X=61.24 kilometers. Before the break-even point, road transport has lower cost because there is no modal transfer cost required. On the other hands, cargoes shipped with rail usually need to change transport mode. This can be witnessed in the case study presented before where the container has to be transferred from road to rail at a train station because of limited accessibility. As a result, from zero to sixty first kilometer road has lower transport cost than rail. However, when the distance reaches 61 kilometers, which is a break-even point of road and rail, the total cost of road transport exceeds that of rail since rail has lower average cost per kilometer. The result refers that road is the most economical mode of transporting goods with distance of less than 61 kilometers. Beyond the 61-kilometer distance, rail will become more economical.

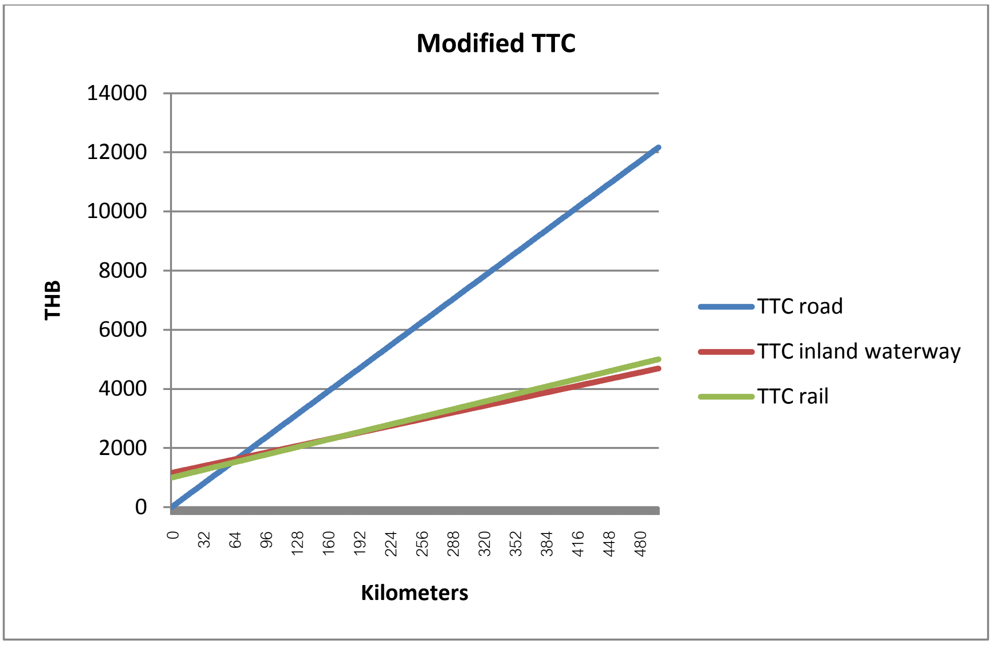
Figure 4.7: Modified models of rail and inland waterway transport



Source: The author

The cost of transporting a twenty-foot container via inland waterway is slightly higher than rail at the zero kilometer because handling costs of inland waterway is more expensive. The higher handling cost of inland waterway is due to a substantial amount of investment required in infrastructure of the ports such as quay walls and quay cranes, while rail freight station requires less investment. Although the modal transfer cost of inland waterway is more expensive, the average transport cost per kilometer is lower than rail. This can be witnessed by the lower steepness of the cost line of inland waterway than rail. The equations of inland waterway and rail suggest that the intersection, which is the break-even point of the two transport modes, is at X = 170.21 or 170th kilometer. This means that the total transport cost of rail from 0 to 170 kilometers is lower than inland waterway. Nonetheless, beyond the break-even point at 170th kilometer, the total transport cost of rail exceeds the total transport cost of inland waterway.

Figure 4.8 Modified models of road, rail, and inland waterway transport



Source: The author

When the three cost lines of all transport modes are plotted together, the model illustrates that the first break-even point is between road and rail at X = 61.24 or 61.24th kilometer. The second break-even point is between road and inland waterway at X = 67.17 or 67.17th kilometer. And the last break-even point is between inland waterway and rail at X = 170.21 or 170.21st kilometer. The model suggests that to transport a container with distance of less than 61.24 kilometers, the most economical mode is road. For transport of more than 61.24 kilometers but less than 67.17 kilometers, rail is the most economical mode. And finally, inland waterway is the most economical mode of transporting a cargo, or a container in this case, for more than 170.21 kilometers in distance.

The aim of this initial model is to illustrate the concept of cost curve construction. However, the assumption of no bridging transport cannot properly reflect reality because transfer nodes for rail and inland waterway are usually not located adjacent to user’s premises. Therefore, bridging transport, which is transport of a cargo from an origin or a destination to a transfer node, is required. The bridging transport is normally carried out via roads as in the case study and this operation also causes additional costs. Consequently, to be able to model the transport correctly, the bridging transport has to be taken into account as well.

If it is assumed that the total distance is 200 kilometers and bridging transport of 30 kilometers is required, a model comparing road and rail transport can be constructed as follows:

For road transport, the equation remains the same

$$Y = 24.33X$$

For rail transport, the cost equation from zero kilometer to thirtieth kilometer is taken from cost equation of road, because the transport in this leg is assumed to be carried out via roads, combines with the cost of modal transfer of rail. The equation is

$$Y = 1000 + 24.33X$$

At the transfer node where X = 30, the total transport cost is

$$Y = 1729.9$$

At the first kilometer of rail transport, where X = 31, the average transport cost per kilometer is THB 8 and the total cost at the thirty first kilometer is = 1,729.9 + 8 = 1737.9

At this point, it is clear that where X = 31, Y = 1,737.9

Thus, a constant (C) can be found by

$$Y = 8X + C$$

$$1737.9 = 248 + C$$

$$1489.9 = C$$

Consequently, the cost equation of rail transport is

$$Y = 8X + 1489.9$$

Now, an intersection of road and rail can be identified by deducting the cost equation of road with the cost equation of rail

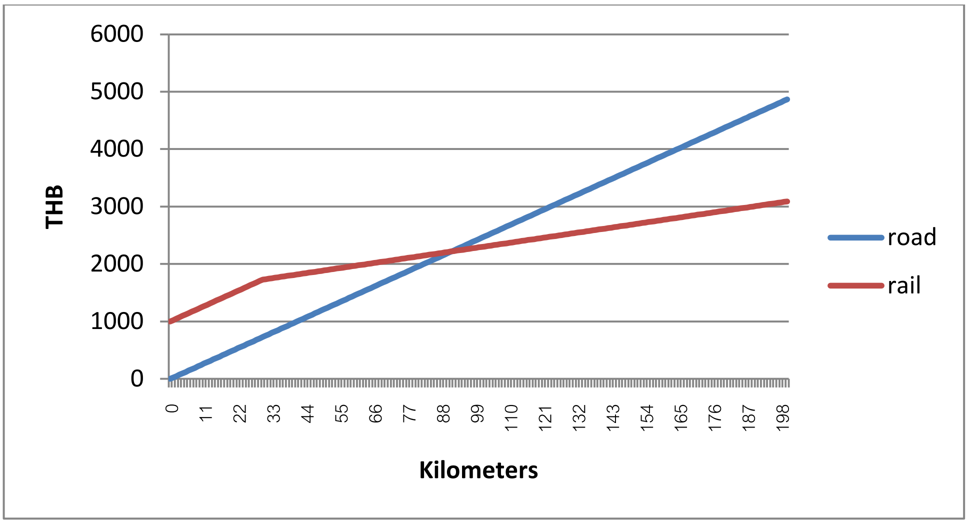
Road – Rail:

$$116.33X = -1489.9$$

$$X = 91.237$$

The intersection, which is the break-even point of road and rail, is at X = 91.237 or 91.24th kilometer. This means that the cost of rail transport is higher than road until the distance reaches 91.24 kilometers as shown in figure 4.9.

Figure 4.9 Alternative model of rail transport



Source: The author

The model can be validated by using a traditional cost model. From a warehouse or shipper's premise to a train station (the bridging transport), the cost of this leg is 24.33*30 = THB 729.9. At the train station, a charge of THB 550 is collected and the total cost of rail haulage is 8*170 = THB 1360, and a rail transfer charge of THB 450 at the port. The total transport cost of rail in this case is thus = 729.9 + 550 + 1360 + 450 = THB 3089.9 which is equal to the outcome from the model where Y = 8(200) + 1,489.9 = THB 3,089.9

Table 4.1 Verification of the model using traditional cost model method (1)

Leg	Mode	Distance (KM)	Cost (THB)	Total Cost (THB)	Accumulated Total Cost (THB)
Warehouse - Train Station	Road	30	24.33/km	729.9	729.9
Train Station: Handling charge		0	550	550	1279.9
Train Station - Sea Port	Rail	170	8/km	1360	2639.9
Sea Port: Rail transfer charge		0	450	450	3089.9
Total		200		3089.9	

Source: The author

The distance of bridging transport of 30 kilometers can be a summation of transport at anywhere in the route. For example, if there are two bridging transport with 15 kilometers each at the beginning and the end instead of 30 kilometers of distance at the beginning of the haulage, the total transport cost is still THB 3,089.9 as shown in the table below.

Table 4.2 Verification of the model using traditional cost model method (2)

Leg	Mode	Distance (KM)	Cost (THB)	Total Cost (THB)	Accumulated Total Cost (THB)
Warehouse - Train Station	Road	15	24.33/km	364.95	364.95
Train Station: Handling charge		0	550	550	914.95
Train Station - Sea Port	Rail	170	8/km	1360	2274.95
Sea Port: Rail transfer charge		0	450	450	2724.95
Road Haulage	Road	15	24.33/km	364.95	3089.9

Source: The author

As a result, a cost equation of rail transport when there are 30 kilometers of bridging transport via roads can be identified as:

$$TTC\ rail \begin{cases} 24.33X + 1000; 0 < X \leq 30 \\ 8X + 1489.9; X \geq 30 \end{cases}$$

Or it can be generalized as

$$TTC\ teu \begin{cases} ACbt \times X + TCmt; 0 < X \leq a \\ ATCteu - km + Cmi; X \geq a \end{cases}$$

(4.2)

Where a is the distance of bridging transport.

And with the same concept, a cost equation of inland waterway can be constructed. The equation where X<=bridging distance or X<=30 in this example is the cost equation of road which is Y = 24.33X and the total modal transfer cost of THB 1,160 or Y = 24.33X + 1,160

At the transfer node where X = 30, the total transport cost is

$$Y = 24.33 \times 30 + 1160 = 1889.9$$

At the first kilometer of rail transport, where X = 31, the average transport cost per kilometer is THB 7.06 and the total cost at the thirty first kilometer is = 1,889.9 + 7.06 = 1,896.96

At this point, it is clear that where X = 31, Y = 1,896.96

Thus, a constant (C) can be found by

$$Y = 7.06X + C$$
$$1896.6 = 218.86 + C$$

$$1678.1 = C$$

Consequently, the cost equation of rail transport is Y = 7.06X + 1,678.1

Thus, a cost equation of rail transport when there are 30 kilometers of bridging transport via roads can be identified as:

$$Y \begin{cases} 24.33X + 1160; 0 < X \leq 30 \\ 7.06X + 1678.1; X \geq 30 \end{cases}$$

An intersection of road and rail can be identified by deducting the cost equation of road with the cost equation of rail

Road – Inland waterway:

$$-17.27X = -1678.1$$

$$X = 97.17$$

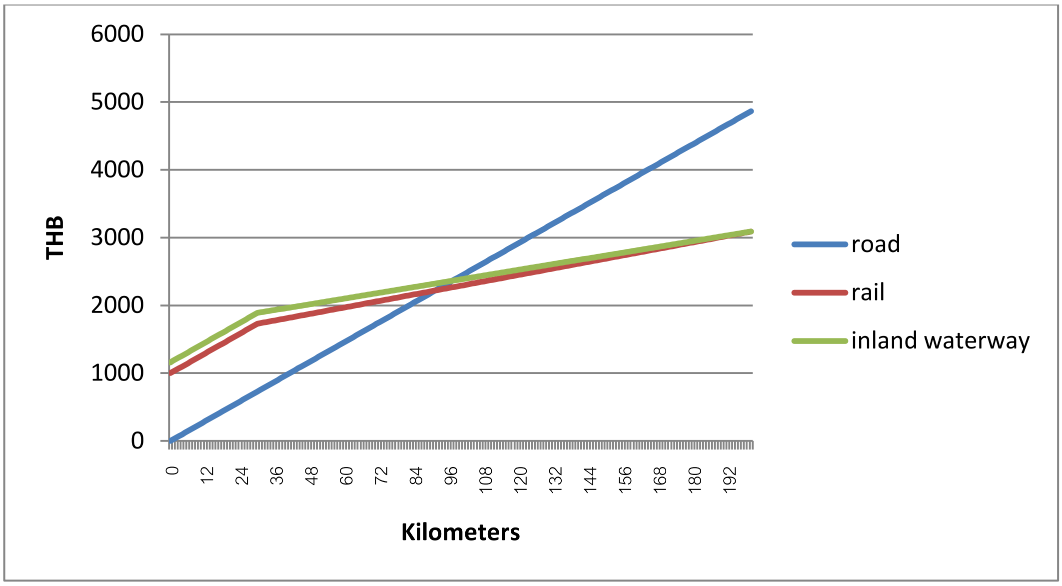
Rail – Inland waterway:

$$-0.94X = -188.2$$

$$X = 200.21$$

The intersection, which is the break-even point of road and inland waterway, is at X = 97.17 or 97.17th kilometer, and the break-even point of rail and inland waterway is at X = 200.21 or 200.21st kilometer. This means that the cost of inland waterway transport is higher than road until the distance reaches 97.17 kilometers and is higher than rail until the distance surpasses 200.21 kilometers.

Figure 4.10 Alternative models of road, rail, and inland waterway transport



Source: The author

The previous assumption holds that the distance of bridging transport is counted as a part of the distance of the total transport i.e. the distance of the main haul rail transport decrease as the distance of the bridging road transport increases. However, most of the time the distance between transfer nodes such as from station A to station B or port A to port B is fixed and bridging transport dose not actually reduce the distance of main haulage. The model thus has to be modified again by adding the cost of bridging transport to the constant variable of the cost equation. The new modified equation for the model can be denoted as

$$TTCteu = (ATCteukm \times X) + (TCmt + TCbt) \tag{4.3}$$

The total cost of bridging transport (TC_{BT}) is equal to the average cost of bridging transport per kilometer (AC_{BT}) multiplied by the distance of bridging transport in kilometers (KM_{BT}). The value average cost of bridging transport depends on the mode of bridging transport i.e. road.

$$TCbt = ACbt \times Distance\ of\ Bridging\ Transport$$

$$TCbt = ACbt \times KMbt \tag{4.4}$$

With this assumption, the cost equation of rail transport (TTC rail) is hence

$$TTC\ rail = 8X + (1000 + TCbt)$$

If the distance of bridging transport is 30 kilometers and the mode of bridging transport is road, the TTC rail equation is

$$TTC\ rail = 8X + \big(1000 + (24.33 \times 30)\big)$$

$$TTC\ rail = 8X + 1729.9$$

Because road transport does not require bridging transport, the TTC road equation remains the same.

$$road = 24.33X$$

Inland waterway does require bridging transport to provide access to cargoes. As a result, with 30 kilometers of bridging transport via road, the TTC inland waterway equation is

$$TTC\ inland\ waterway = 7.06X + \big(1160 + (24.33 \times 30)\big)$$

$$TTC\ inland\ waterway = 7.06X + 1889.9$$

Again, the traditional cost model approach is used to validate the result of the modified equation. The modified model provides that the total transport cost of rail is Y = 8(200) + 1,729.9 = 3,329.9

Table 4.3 Verification of the model using traditional cost model approach (3)

Leg	Mode	Distance (KM)	Cost (THB)	Total Cost (THB)	Accumulated Total Cost (THB)
Warehouse - Train Station	Road	30	24.33/km	729.9	729.9
Train Station: Handling charge		0	550	550	1279.9
Train Station - Sea Port	Rail	200	8/km	1600	2879.9
Sea Port: Rail transfer charge		0	450	450	3329.9
Total		230		3329.9	

Source: The author

Using the traditional cost model approach, the result is identical to the outcome from the equation. Thus, the modified model and its equation are validated.

Table 4.4 Verification of the model using traditional cost model approach (4)

Leg	Mode	Distance (KM)	Cost (THB)	Total Cost (THB)	Accumulated Total Cost (THB)
Warehouse - Train Station	Road	15	24.33/km	364.95	364.95
Train Station: Handling charge		0	550	550	914.95
Train Station - Sea Port	Rail	200	8/km	1600	2514.95
Sea Port: Rail transfer charge		0	450	450	2964.95
Road Haulage	Road	15	24.33/km	364.95	3329.9
Total		230		3329.9	

Source: The author

Table 4.5 Verification of the model using traditional cost model approach (5)

Leg	Mode	Distance (KM)	Cost (THB)	Total Cost (THB)	Accumulated Total Cost (THB)
Warehouse - Train Station	Road	20	24.33/km	486.6	486.6
Train Station: Handling charge		0	550	550	1036.6
Train Station - Sea Port	Rail	200	8/km	1600	2636.6
Sea Port: Rail transfer charge		0	450	450	3086.6
Road Haulage	Road	10	24.33/km	243.3	3329.9
Total		230		3329.9	

Source: The author

Table 4.6 Verification of the model using traditional cost model approach (6)

Leg	Mode	Distance (KM)	Cost (THB)	Total Cost (THB)	Accumulated Total Cost (THB)
Warehouse - Train Station	Road	7	24.33/km	170.31	170.31
Train Station: Handling charge		0	550	550	720.31
Train Station - Sea Port	Rail	200	8/km	1600	2320.31
Sea Port: Rail transfer charge		0	450	450	2770.31
Road Haulage	Road	23	24.33/km	559.59	3329.9
Total		230		3329.9	

Source: The author

Table 4.4, 4.5, and 4.6 illustrate that the bridging transport can occur at anywhere in the haulage as long as it does not cause an additional handling or modal transfer costs. The table also shows the robustness of the model as the distance of bridging transport can vary but the modified model still provide the same outcome.

With the modified total transport cost equation of road, rail, and inland waterway; intersections of the three modes can be found by

Road and rail:

$$X = 105.93$$

The intersection or the break-even point of road and rail is at $X = 105.93$ or 105.93rd kilometer.

Road and inland waterway:

$$X = 115.38$$

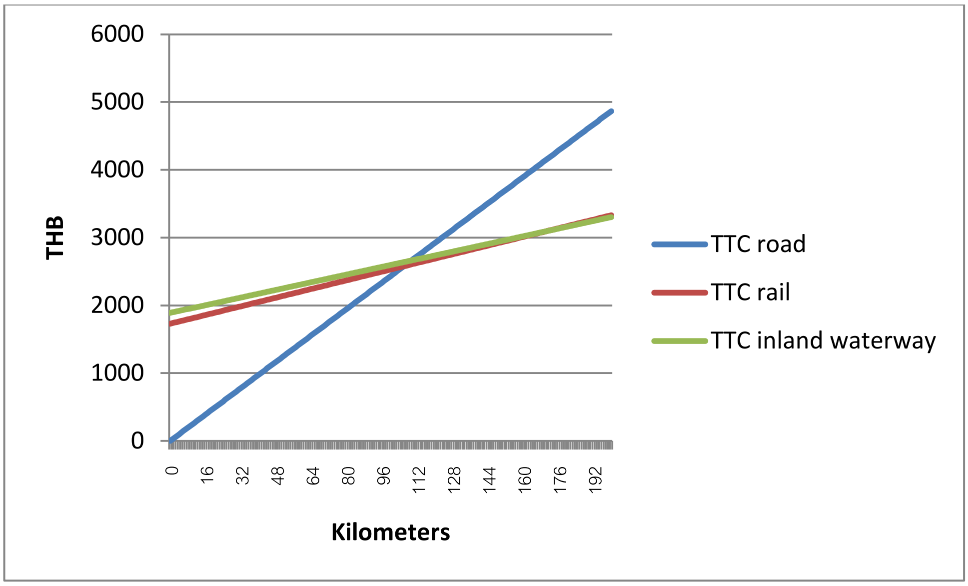
The intersection or the break-even point of road and inland waterway is at $X = 115.38$ or 115.38th kilometer.

Rail and inland waterway:

$$X = 170.21$$

The intersection or the break-even point of rail and inland waterway is at $X = 170.21$ or 170.21st kilometer.

Figure 4.11 Alternative models of road, rail, and inland waterway transport



Source: The author

A formula for indicating a break-even point of two transport modes (BE_{m1} and BE_{m2}) can be identified as

$$BEmi,mj = \frac{Cmi - Cmj}{(ATCmj - ATCmi)}$$

(4.5)

C_{mi} stands for the value of a constant in cost equation of transport mode i which is a summation of total cost of multimodal transfer of mode i and total cost of bridging transport of mode i.

$$Cmi = TCmti + TCbti$$

(4.6)

ATC_{mi} stands for the value of a in a cost equation ($y = ax + c$), which is the average transport cost per kilometer of that mode. The value of ATC_{mi} is equal to 24.33 for road transport, 8 for rail, and 7.06 for inland waterway.

The model suggests that for a transport of one twenty-foot container less than 105.93 kilometers, road is the most economical mode because road has lower transport cost than rail and inland waterway. However, transport costs of road exceeds rail when the distance reaches 105.93 kilometers and the transport costs of road exceeds inland waterway when the distance reaches 115.38 kilometers. And the transport cost of rail exceeds the transport cost of inland waterway when the distance reaches 170 kilometers. This means, in terms of modal competition between transport modes, road is the most economical mode of transporting a twenty-foot container from 0 to 105.93 kilometers. From 105.93 to 170 kilometers, rail is the most economical mode. And for freight transport of more than 170 kilometers, inland waterway is the most economical mode.

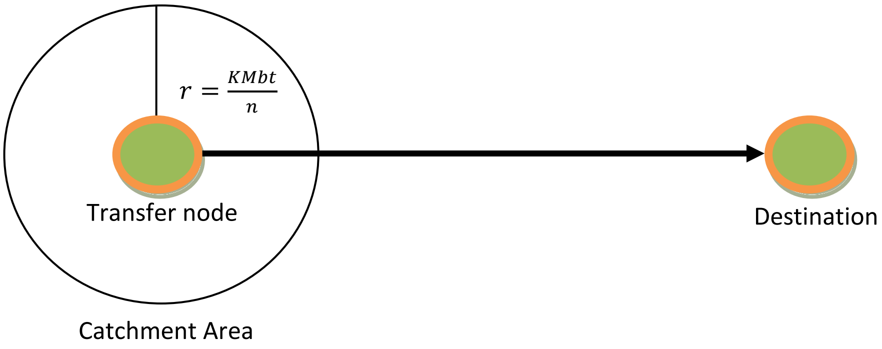
The result can be interpret that, firstly, a cost advantage of rail occurs when the total transport distance of a cargo (container) is longer than 105.93 or 106 kilometers, and the cost advantage of inland waterway occurs when the transport distance of a container exceeds 170 kilometers. When there are two alternative transport modes available, for example road and rail, total transport cost is minimized when hauling a twenty-foot container box via roads for a distance of less than 105.93 kilometers. But if the distance is more than 105.93 kilometers, the total transport cost is minimized when the cargo is carried by a train. In a modal competition between road and inland waterway, road has a cost advantage if the distance is less than 115.38 kilometers. And when the distance passes 115.38 kilometers, inland waterway has a cost advantage over road transport. Secondly, the result refers that a market target or a potential customer of rail transport is cargoes which have to travel more than 105.93 kilometers and 170 kilometers for inland waterway. And thirdly, the distance of bridging transport is a determinant of a radius that the break-even points will be feasible. The bridging distance of 30 kilometers suggests that a captive area for a modal transfer node such as a train station or a port has a radius of up to 30 kilometers.

The catchment can be found by using a formula (in case of symmetric distance)

$$Radius\ (r) = \frac{KMbt}{Nbt} \tag{4.7}$$

Where N_{BT} is a number of legs that bridging transport occurs. For example, if there is only one bridging transport from a warehouse to the transfer node, the potential target market of a river port is are cargoes that their destination is more than 138 kilometers away or 171 kilometers in case rail transport is available in the same route and the warehouse or customer' premise is located within a parameter of 30 kilometers from the port. But if there are two bridging transport i.e. 15 kilometers from the warehouse to the origin transfer node and 15 kilometers from the destination transfer node to final destination, the parameter of the catchment area is $\frac{30}{2}$ = 15 kilometers.

Figure 4.12 Radius of a catchment area (symmetric)



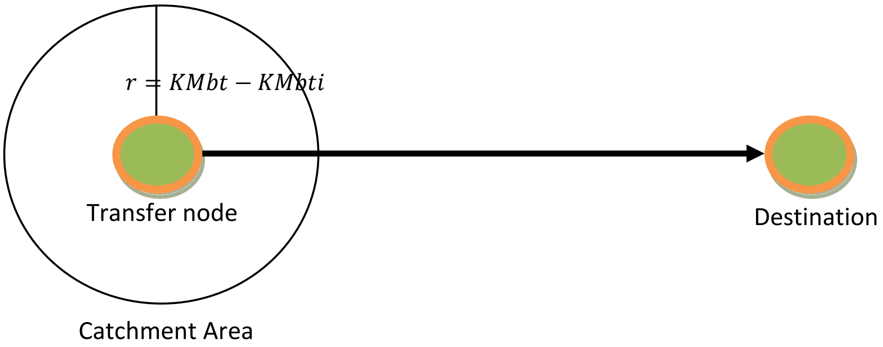
Source: The author

Or in case of asymmetric distance:

$$Radius\ of\ node\ j\ (rj) = KMbt - KMbti \tag{4.8}$$

A catchment area of node j can be found by deducting the total distance of bridging transport (KM_{BT}) by the distance of bridging transport of node i (KM_{BTi}). For example, if the total distance of bridging transport (KM_{BT}) is 30 (i.e. when the model is calculated based on KM_{BT} = 30), and the distance of bridging transport of node i (KM_{BTi}) is 20. Then the radius of node j is 10 kilometers.

Figure 4.13 Radius of a catchment area (asymmetric)



Source: The author

A positive relationship exists between the level of break-even points and the distance of bridging transport. The break-even points changes according to varying distance of bridging transport, except the break-even point of rail and inland waterway which has a constant value of 170.21 kilometers because the two lines shift together as the distance of bridging transport changes. Table 4.7 exhibits that when the distance of bridging transport is 0; the break-even points of road and rail, and road and inland waterway are at 61.24th, and 67.71st kilometer. When the distance of bridging transport increases to 20 kilometers, the break-even points of road and rail, and road and inland waterway escalate to 91.03rd, and 95.34th kilometer. And if the distance of bridging transport expands to 100 kilometers, the break-even points of road and rail, and road and inland waterway rise to 210.23, and 208.05 kilometers.

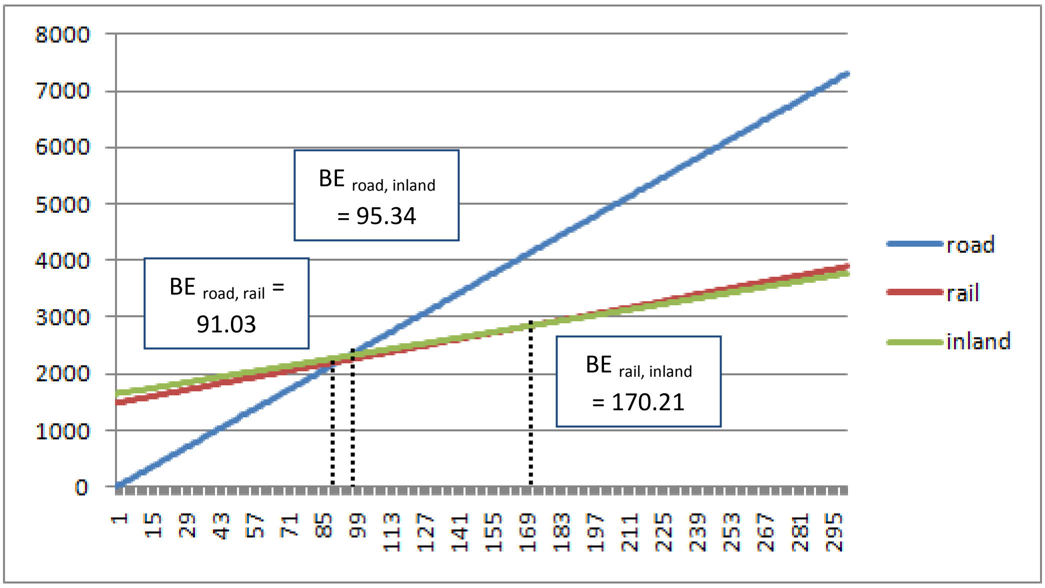
This sensitivity analysis of the relationship between distance of bridging transport and break-even point demonstrates that as the size of catchment area increases, the transport distance of potential cargoes must increases as well. For instance, if a shipper is located 20 kilometers away from a railway station, a customer will consider using rail transport when the cargo has to travel for more than 91.03 kilometers because beyond this point the rail option starts to provide a benefit from lower cost. On the other hands, if the shipper is located 100 kilometers away, the transport distance of the cargo must exceed 210.23 kilometers for the shipper to consider the rail freight service. To clarify the term “shipper”, the shipper in this case refers to a person or organization or company who pays for the freight transport service, which can be either a seller or a buyer depending on a trade agreement or INCOTERMS or even a third-party logistics service provider who arranges the transport.

Table 4.7 Sensitivity analysis of break-even points

Mode	**Break-even point (Fuel Price = THB 30/liter)**				
	$KM_{BT} = 0$	**$KM_{BT} = 20$**	**$KM_{BT} = 30$**	**$KM_{BT} = 50$**	**$KM_{BT} = 100$**
Road/ Rail	61.24	91.03	105.93	135.73	210.23
Road/ Inland waterway	67.17	95.34	109.43	137.61	208.05
Rail/ Inland waterway	170.21	170.21	170.21	170.21	170.21

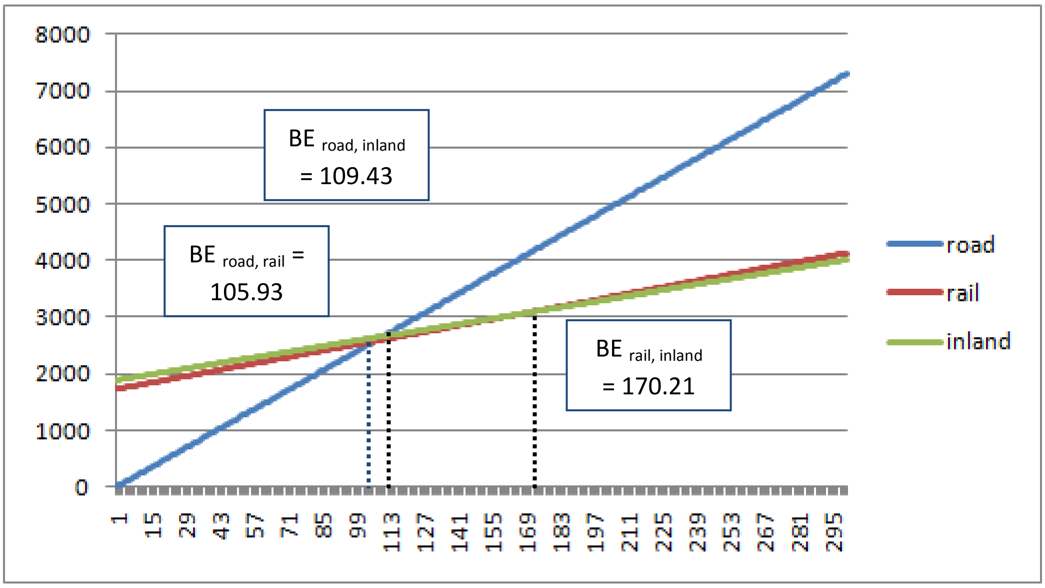
Source: The author

Figure 4.14 Break-even points when KM_{BT} = 20



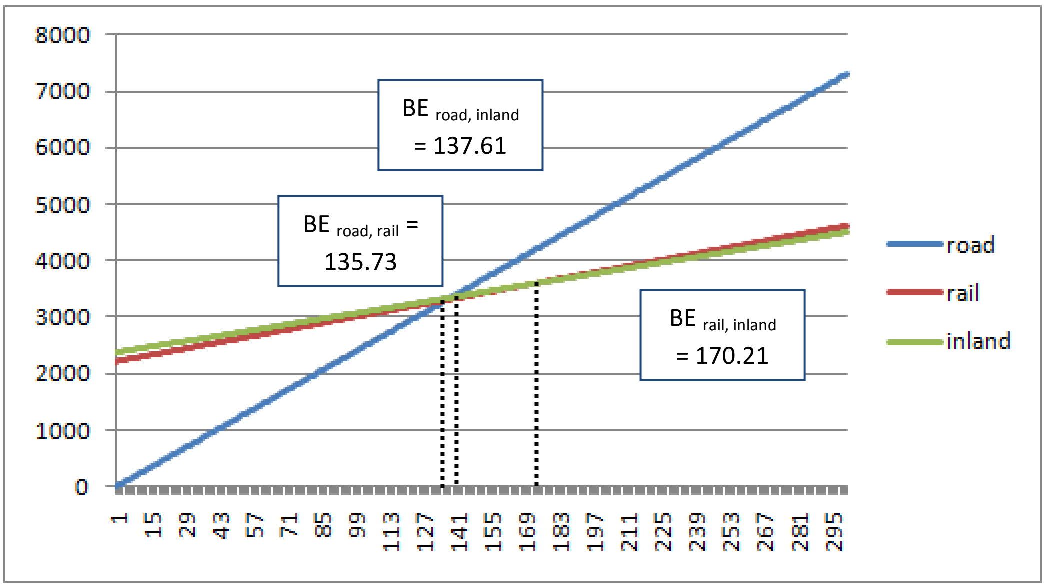
Source: The author

Figure 4.15 Break-even points when KM_{BT} = 30



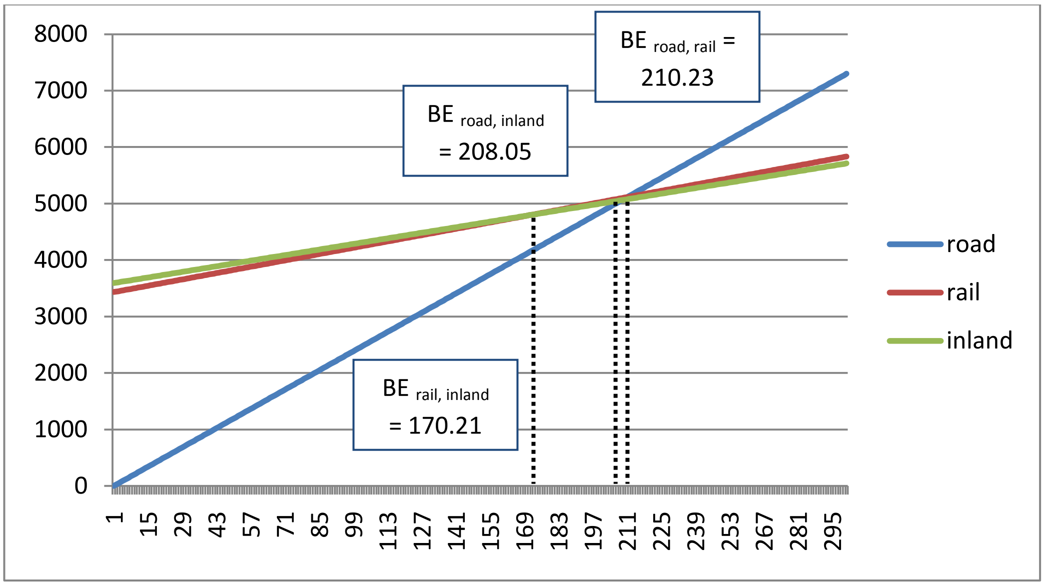
Source: The author

Figure 4.16 Break-even points when KM_{BT} = 50



Source: The author

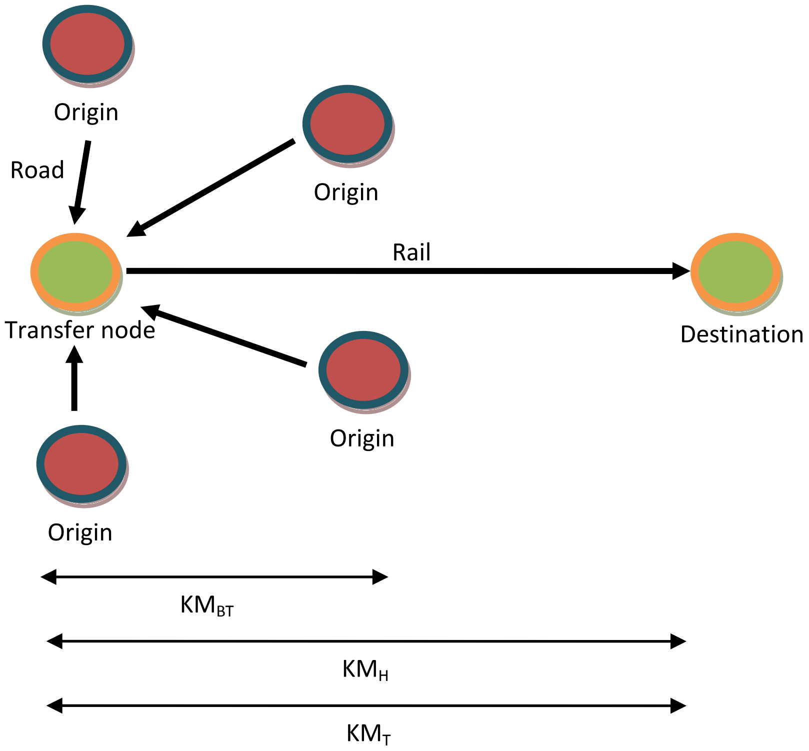
Figure 4.17 Break-even points when KM_{BT} = 100



Source: The author

The different between equation 4.2 and 4.3 is: in the equation 4.3, the distance of bridging transport (KM_{BT}) is excluded from the total distance. An example of this case is when the bridging transport creates additional distance to the total distance i.e. the cargo has to detour to a modal transfer node or when KM_H is equal to KM_T.

Figure 4.18 Application of the model (1)

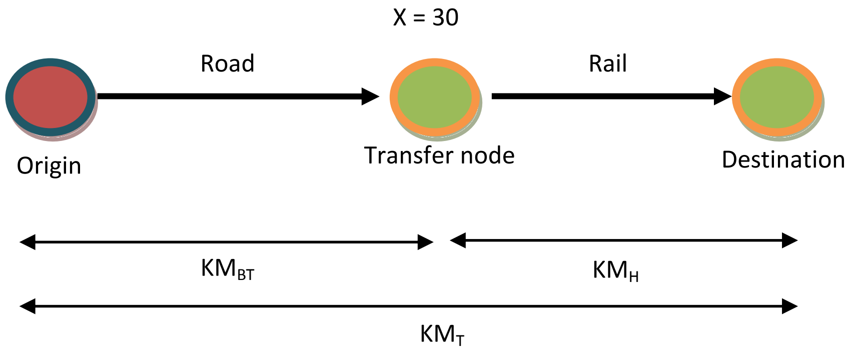


$$TTCteu = (ATCteukm \times X) + (TCmt + TCbt)$$

Source: The author

On contrary, if the distance of bridging transport is included in the total distance (KM_T). And the total distance is equal to the distance of bridging transport + the distance of main haul or KM_{BT} + KM_H. For instance, the distance from the warehouse in Nakorn Luang to Lad Krabang Inland Container Depot is 100 kilometers ($KM_{BT} = 100$) and the distance from Lad Krabang ICD to Laem Chabang Port is 94 kilometers ($KM_H = 94$). Thus, the total distance (KM_T) is 194 kilometers. In such case, the equation 4.2 shall be applied to provide better accuracy. The reason why the equation 4.2 is more appropriate than the equation 4.3 for transport with this characteristic is that the equation 4.3 will present a misleading value of distance (X). From the example, if the equation 4.3 is adopted, the value of X will be 94 kilometers with bridging transport of 100 kilometers instead of X being 194 kilometers.

Figure 4.19 Application of the model (2)



$$TTC\ teu \begin{cases} ACbt \times X + TCmt; 0 < X \leq a \\ ATCteu - km + Cmi; X \geq a \end{cases}$$

Source: The author

4.2 Chapter conclusion

In this Chapter, the transport cost (TTC_{TEU}) equation is rewritten in a linear form to facilitate identifications of break-even points. To construct a linear equation, all fixed costs must be assumed to occur at the beginning of the transportation or when the distance (X variable) equals zero. When assumes that bridging transportation is not required, the new Total Transport Cost equation of road transport (TTC road) is 24.33X, the new Total Transport Cost equation of rail (TTC rail) is 8X + 1,000, and the new Total Transport Cost equation of inland waterway (TTC inland waterway) is 7.06 + 1,160.

There are, however, three equations for calculating total transport cost and identifying intersections. The assumptions are: when there is no bridging transportation, the appropriate equation is 4.1; when the distance of bridging transport is included in the total distance, the appropriate equation is 4.2; and when the distance of bridging transport is excluded from total distance, equation 4.3 will provide the most accurate answer.

Break-even points are intersections between cost lines of different transport modes. Given distance in kilometers as an X variable, the intersections of the cost lines refer to the distances (X values) where the intersecting modes have equal total transport cost. The intersections help determining the distance where different modes can equally compete in terms of costs. The distance of bridging transport has a direct relationship with the distance of the intersection: the longer the bridging transport distance, the longer the distance of the intersection (the value of the X variable). This is because the mode of bridging transport is usually road which has the highest average cost per kilometer. Table 4.7 illustrates sensitivity analysis when the distances of bridging transport (KM_{BT}) change. Intermodal competition can be analyzed using the results from the model in table 4.7. When $KM_{BT} = 30$, road is the most economical mode for transporting goods for less than 135.73 kilometers. Rail will have lower total transport cost than road when the distance reaches 135.73 kilometers and become the most economical mode until the distance exceeds 170.21 kilometers where the total transport cost of rail will be higher than inland waterway.

The distance of bridging transportation also provides useful information, it identifies radius of potential catchment area of a transfer node, which can be calculated by equation 4.7 and 4.8. This should be enough to assist transfer node operators to locate and determine their potential cargoes and target markets.

Chapter 5 Application of the Model

5.1 Application

According to the National Statistical Office (National Statistical Office, 2010), twenty provinces with highest nominal Gross Provincial Product in 2009 are Bangkok, Samut Prakarn, Phra Nakhon Sri Ayudhaya (Ayudhaya), Chon Buri, Rayong, Samut Sakorn, Pathum Thani, Chachoengsao, Saraburi, Khon Kaen, Nakhon Rajasima, Songkla, Nakhon Pathom, Nonthaburi, Chiang Mai, Nakhon Sri Dhammaraj, Surat Thani, Rajaburi, Kamphaeng Phet, and Lamphun. The GPP of the twenty provinces accounts for seventy seven percent of the nominal national Gross Domestic Product. The statistics refers that approximately 77% of Thailand’s economic activities are concentrated in these twenty out of seventy six provinces and 25% of the national GDP occurs in Bangkok. This means Bangkok is the largest consumption and production area in Thailand followed by the next 19 provinces. Because Of the derived demand in transport, a large economic area implies that there is also high traffic flows and high demand in transport. Of the twenty provinces, all of them are connected by road and rail networks, however, the railway network in Thailand is relatively underdeveloped and most of the rails are single-tracks. Seven provinces: Bangkok, Samut Prakarn, Phra Nakorn Sri Ayudhaya, Samut Sakorn, Pathum Thani, Chachoengsao, and Nonthaburi have accesses to navigable inland waterways. A majority of these provinces: Bangkok, Samut Prakarn, Ayudhaya, Pathum Thani, and Nonthaburi are connected to River Chaopraya while Samut sakorn is connected to River Mae Klong, and Chachoengsao is connected to River Bang Pakong.

Table 5.1 Twenty provinces with highest Gross Provincial Product in Thailand

THB million

Provinces	Nominal GPP	% of National GDP
Bangkok	1,071,242	25%
Samut Prakan	365,190	9%
Phra Nakhon Si Ayutthaya	251,600	6%
Chon Buri	250,238	6%
Rayong	231,619	5%
Samut Sakhon	183,711	4%
Pathum Thani	123,399	3%
Chachoengsao	111,916	3%
Saraburi	74,556	2%
Khon Kaen	73,081	2%
Nakhon Ratchasima	69,336	2%
Songkhla	66,798	2%
Nakhon Pathom	60,313	1%
Nonthaburi	57,533	1%
Chiang Mai	53,693	1%
Nakhon Si Thammarat	53,175	1%
Surat Thani	51,771	1%
Ratchaburi	45,912	1%
Kamphaeng Phet	36,675	1%
Lamphun	36,382	1%
Total top 20	3,268,140	77%
Total National GDP	**4,263,363**	

Source: Adapted from National Statistical Office (2010)

Industrial estates are also located in the same areas where Gross Provincial Product is high. The industrial estates are important production sources which induce inflow transport of raw materials and semi-finished goods and outflow transport of finished goods at the same time. Production facilities are usually concentrated in the industrial estates because of the benefits from clustering, infrastructure development, and including tax incentives from the government. The map in the Appendix VI displays that a significant number of the existing industrial estates scatter around the Eastern and the Central regions.

Table 5.2 represents distances in Kilometers between the top 20 GPP provinces and Laem Chabang Port (LCP) and Bangkok (BKK). Laem Chabang Port is the largest container port of Thailand and is the gateway for Thailand's exports to as well as imports from the international market. As a result, most of the containerized cargoes are transported from production facilities across Thailand, especially the production facilities in the industrial areas. And because Bangkok is the largest consumption area in the country in terms of Gross Domestic Product, the distance to Bangkok implies to the distance from producers in other industrial provinces to the major consumer market.

Table 5.2 Road distances between the top-twenty provinces and Bangkok and Laem Chabang Port

Distance in KM

Provinces	to LCP	to BKK (LKR)
Bangkok (LKR)	94	-
Samut Prakan	86	17
Phra Nakhon Si Ayutthaya	182	92
Chon Buri	53	93
Rayong	92	155
Samut Sakhon	160	82
Pathum Thani	138	48
Chachoengsao	141	126
Saraburi	207	117
Khon Kaen	448	408
Nakhon Ratchasima	316	287
Songkhla	1,063	985
Nakhon Pathom	192	102
Nonthaburi	150	61
Chiang Mai	839	748
Nakhon Si Thammarat	847	770
Surat Thani	772	695
Ratchaburi	236	159
Kamphaeng Phet	460	370
Lamphun	712	622

Source: Adapted from GoogleMaps (2010)

Since the model suggests that, with 30 kilometers of bridging transport, the break-even point of Road and Rail is 105.93 or 106 kilometers. The distance table illustrates that potential routes where rail transport is attractive in terms of cost are to and from Laem Chabang Port to the following provinces: Bangkok (130), Ayudhaya (182), Samut Sakorn (160), Pathum Thani (138), Chachoengsao (141), Sara Buri (207), Khon Kaen (448), Nakorn Rajasima (316), Songkla (1,063), Nakorn Pathom (192), Nonthaburi (150), Chiang Mai (839), Nakhon Sri Dhammarat (847), Surat Thani (772), Rajaburi (236), Kamphaeng Phet (460), and Lam Phun (712). This means there are at least 17 potential locations to develop freight modal transfer points between road and rail in order to reduce the national transport and logistics costs of exports and imports. The distance to and from Bangkok is the distance to Lad Krabang Inland Container Depot. Lad Krabang ICD is selected as a transfer node for Bangkok because there is existing facilities available in the ICD and it is located close to major industrial estates of Bangkok: Lad Krabang industrial estates, Gemopolis industrial estates, and Bang Chan industrial estates. The proximity to industrial estates provides additional cost advantage because of low cost of bridging transport and shorter transit time to and from the transfer node.

Table 5.3 Projected cost saving from modal shifts using the results from the model (1)

Provinces	**To LCP**				
	Road	**Rail KM_{BT} = 30**	**% Reduction**	**Rail KM_{BT} = 50**	**% Reduction**
Bangkok	2,287	2,482	-9%	2,969	-30%
Samut Prakan	2,092	2,418	-16%	2,905	-39%
Phra Nakhon Si Ayutthaya	4,428	3,186	28%	3,673	17%
Chon Buri	1,289	2,154	-67%	2,641	-105%
Rayong	2,238	2,466	-10%	2,953	-32%
Samut Sakhon	3,893	3,010	23%	3,497	10%
Pathum Thani	3,358	2,834	16%	3,321	1%
Chachoengsao	3,431	2,858	17%	3,345	3%
Saraburi	5,036	3,386	33%	3,873	23%
Khon Kaen	10,900	5,314	51%	5,801	47%
Nakhon Ratchasima	7,688	4,258	45%	4,745	38%
Songkhla	25,863	10,234	60%	10,721	59%
Nakhon Pathom	4,671	3,266	30%	3,753	20%
Nonthaburi	3,650	2,930	20%	3,417	6%
Chiang Mai	20,413	8,442	59%	8,929	56%
Nakhon Si Thammarat	20,608	8,506	59%	8,993	56%
Surat Thani	18,783	7,906	58%	8,393	55%
Ratchaburi	5,742	3,618	37%	4,105	29%
Kamphaeng Phet	11,192	5,410	52%	5,897	47%
Lamphun	17,323	7,426	57%	7,913	54%

Source: The author

Using the equation TTC road = 24.33X and TTC rail = 8X + 1,729.9 (when KM_{BT} = 30), road and rail transport costs between the major 20 provinces and Laem Chabang Port are obtain as illustrated in the table 5.3. The result indicates that there are 16 potential provinces for rail freight transport development. And if freight transport mode is shifted from road to rail, there will be a reduction in the transport costs between Laem Chabang Port and the following provinces (when the distance of bridging transport is 30 kilometers): Ayudhaya (28%), Samut Sakhon (23%), Pathum Thani (16%), Chachoensao (17%), Saraburi (33%), Khon Kaen (51%), Nakhon Rajasima (45%), Songkla (60%), Nakhon Pathom (30%), Nonthaburi (20%), Chiang Mai (59%), Nakhon Sri Dhammarat (59%), Surat Thani (58%), Rajaburi (37%), Khampaeng Phet (52%), and Lamphun (57%). And when the distance of bridging transport is assumed to be 50 kilometers, there will be reductions in transport costs between Laem Chabang Port and the following provinces: Ayudhaya (17%), Samut Sakhon (10%), Pathum Thani (1%), Chachoensao (3%), Saraburi (23%), Khon Kaen (47%), Nakhon Rajasima (38%), Songkla (59%), Nakhon Pathom (20%), Nonthaburi (6%), Chiang Mai (56%), Nakhon Sri Dhammarat (56%), Surat Thani (55%), Rajaburi (29%), Khampaeng Phet (47%), and Lamphun (54%). The results align with the break-even points founded in the previous chapter, shifting transport mode from road to rail in provinces that are less than 106 kilometers away from Laem Chabang does not deliver any benefit from cost saving. The cost saving occurs when the distance of ransport exceeds 106 kilometers.

Table 5.4 Projected cost saving from modal shifts using the results from the model (2)

Provinces	**To BKK (LKR)**				
	Road	**Rail KM_{BT} = 30**	**% Reduction**	**Rail KM_{BT} = 50**	**% Reduction**
Samut Prakan	414	1,866	-351%	2,353	-469%
Phra Nakhon Si Ayutthaya	2,238	2,466	-10%	2,953	-32%
Chon Buri	2,263	2,474	-9%	2,961	-31%
Rayong	3,771	2,970	21%	3,457	8%
Samut Sakhon	1,995	2,386	-20%	2,873	-44%
Pathum Thani	1,168	2,114	-81%	2,601	-123%
Chachoengsao	3,066	2,738	11%	3,225	-5%
Saraburi	2,847	2,666	6%	3,153	-11%
Khon Kaen	9,927	4,994	50%	5,481	45%
Nakhon Ratchasima	6,983	4,026	42%	4,513	35%
Songkhla	23,965	9,610	60%	10,097	58%
Nakhon Pathom	2,482	2,546	-3%	3,033	-22%
Nonthaburi	1,484	2,218	-49%	2,705	-82%
Chiang Mai	18,199	7,714	58%	8,201	55%
Nakhon Si Thammarat	18,734	7,890	58%	8,377	55%
Surat Thani	16,909	7,290	57%	7,777	54%
Ratchaburi	3,868	3,002	22%	3,489	10%
Kamphaeng Phet	9,002	4,690	48%	5,177	42%
Lamphun	15,133	6,706	56%	7,193	52%

Source: The author

The modal shift from road to rail also enable transport cost reduction between Bangkok (Lad Krabang) and Rayong (20%), Chachoengsao (11%), Saraburi (6%), Khon Kaen (50%), Nakhon Rajasima (42%), Songkla (60%), Chiang Mai (58%), Nakhon Sri Dhammarat (58%), Surat Thani (57%), Rajaburi (22%), Kamphaeng Phet (48%), and Lamphun (56%) when assumes the distance of bridging transport is 30 kilometers. With bridging transport of 50 kilometers, the cost reductions of transporting a twenty-foot container between Bangkok (Lad Krabang) and Rayong, Khon Kaen, Nakhon Rajasima, Songkla, Chiang Mai, Nakhon Sri Dhammarat, Surat Thani , Rajaburi, Kamphaeng Phet , and Lamphun are 8%, 45%, 35%, 58%, 55%, 55%, 54%, 10%, 42%, and 52% respectively. The increases in the distance of bridging clearly effects the cost savings of the modal shift, this amplifies the importance of proximity between the transfer nodes and the distance to potential demand sources. And the longer the distance of the total transport, the more tolerance the changes in the cost saving results suggested by the model.

Table 5.5 Projected cost saving from modal shifts using the results from the model (3)

Provinces	**To LCP**		
	Road	**Inland waterway**	**% Reduction**
Phra Nakhon Si Ayutthaya	4,428	3,174.82	28%
Samut Sakhon	3,893	3,019.50	22%
Pathum Thani	3,358	2,864.18	15%
Chachoengsao	3,431	2,885.36	16%
Nonthaburi	3,650	2,948.90	19%
Bangkok	3,163	2,807.70	11%
Samut Prakan	2,092	2,497.06	-19%

Source: The author

Shifting freight transport mode from road to inland waterway delivers transport cost reduction as well. The transport costs of inland waterway between Laem Chabang Port and Ayudhaya, Samut Sakhon, Pathum Thani, Chachoengsao, Nonthaburi, and Bangkok are 28%, 22%, 15%, 16%, 19%, and 11% lower than road except Samut Prakarn because the province is only 86 kilometers away from Laem Chabang Port.

Table 5.6 Projected cost saving from modal shifts using the results from the model (4)

Provinces	**To BKK**		
	Road	**Inland waterway**	**% Reduction**
Phra Nakhon Si Ayutthaya	2,238	2,434	-9%
Samut Sakhon	1,995	2,215	-11%
Pathum Thani	1,168	2,201	-88%
Chachoengsao	3,066	3,062	0%
Nonthaburi	1,484	2,137	-44%

Source: The author

However, inland freight transport between Bangkok and Ayudhaya, Samut Sakhon, Pathum Thani, Chachoengsao, and Nonthaburi does not present any cost saving from the modal shift. This is due to the short distances between these provinces and Bangkok.

An important observation is that the mode shift of freight transport can be reduced significantly in the routes between Laem Chabang Port and the following provinces: Ayudhaya (28%), Saraburi (33%), Khon Kaen (51%), Nakhon Rajasima (45%), Songkla (60%), Nakhon Pathom (30%), Chiang Mai (59%), Nakhon Sri Dhammarat (59%), Surat Thani (58%), Rajaburi (37%), Khampaeng Phet (52%), and Lamphun (57%) when the distance of bridging transport is 30 kilometers and : Khon Kaen (47%), Songkla (59%), Chiang Mai (56%), Nakhon Sri Dhammarat (56%), Surat Thani (55%), Khampaeng Phet (47%), and Lamphun (54%) when the distance of bridging transport is 50 kilometers. Moreover, the significant transport cost reductions also exist in the routes between Bangkok and the following provinces (KM_{BT} = 30): Rayong (21%), Khon Kaen (50%), Songkla (60%), Chiang Mai (58%), Nakhon Sri Dhammaraj (58%), Surat Thani (57%), Rajaburi (22%) and Lamphun (56%); and between Bangkok and Khon Kaen (45%), Songkla (58%), Chiang Mai (55%), Nakhon Sri Dhammaraj (55%), Surat Thani (54%), and Lamphun (52%) when KM_{BT} = 50. Although the savings are not significantly high in some provinces i.e. Rayong and Phra Nakhon Sri Ayudhaya, these provinces host several industrial estates that generate large volume of freight transport. Thus, capability to shift transport mode in provinces such as Rayong and Ayudhaya will deliver substantial benefits from cost savings as a result of large quantity effect.

In 2005, the share of modal splits in the National freight transport was only 2% for rail and 6% for inland waterway, while road transport accounted for 87%. Consequently, establishment of modal transfer facilities between road and rail and road and inland waterway in the provinces with high potential cost savings from the modal shift should be considered as first priority because the project will promote meaningful transport cost reductions for Thailand. The recommendation for initial rail development is: the existing North Line from Bangkok to Chiang Mai should be reconstructed to accommodate freight, especially container, transport including building at least one transfer node in Chiang Mai, Kampaeng Phet, Saraburi, Ayudhaya, and Lamphun. Investments in the North East Line should be made at least from Bangkok to Khon Kaen with transfer nodes in Khon Kaen and Nakhon Rajasima. Transfer nodes in the South Line should be primarily located in Songkla, Surat Thani, Nakhon Sri Dhammarat, Rajaburi, and Nakhon Pathom. And finally a transfer node for the East Line in Laem Chabang and Rayong, namely Mabtaphut district, should be established to link the condensed industrial areas with the rest of the country. The results from the model prove that inland waterway transport especially along the River Chaopraya where Ayudhaya, Pathum Thani, Nonthaburi, and Bangkok are located on is more economical than road transport and should receive attention from the policy makers if the policy on modal shift is implemented. However, inland waterway transport from Samut Sakhon and Chachoengsao to Laem Chabang and Bangkok and vice versa involves coastal shipping which is not included in the model, therefore, the results for the two provinces are inconclusive at this point.

The model provides supports for government's policy on modal shift promotion of freight transport since the results obviously suggest that shifting transport mode from road to rail and/or inland waterway will reduce transport cost of the country. One important remark is the modal transfer nodes in provinces where there is an industrial estate should be placed as close as possible to the estate since the industrial estate is a major demand source (the lower the KM_{BT}, the higher the cost saving benefit from the modal shift).

5.2 Chapter Conclusion

The model and the linear cost equation of TTC_{TEU} (Equation 4.3) are adopted in this Chapter to analyze shifts of transport mode from road to rail and road to inland waterway in routes between Laem Chabang Port and Bangkok and Thailand's twenty largest provinces in terms of Gross Provincial Product (GPP). When assumes 30 kilometers distance of bridging transport, the model suggest that there will be significant cost saving (more than 20% transport cost reductions) if flows of containerized cargoes between Laem Chabang Port and Ayudhaya , Saraburi, Khon Kaen, Nakhon Rajasima, Songkla, Nakhon Pathom, Chiang Mai, Nakhon Sri Dhammarat, Surat Thani, Rajaburi, Khampaeng Phet, and Lamphun and between Bangkok and Rayong, Khon Kaen, Nakhon Rajasima, Songkla, Chiang Mai, Nakhon Sri Dhammarat, Surat Thani, Rajaburi, Kamphaeng Phet, and Lamphun are shifted from road to rail. Shifting transport mode from road to inland waterway also provides cost saving benefits, however, because of relatively short distance between Bangkok and the provinces where inland waterway transport is applicable, the modal shift reduces transport costs only in the routes between Laem Chabang Port and Ayudhaya, Pathum Thani, Nonthaburi, Bangkok, and Samut Sakhon.

The results from the model can be applied to assist a transport policy formulation. Firstly, the model proves that shifting transport mode in a number of routes reduces transport costs. Secondly, the model helps identifying potential locations for transfer node establishment and investment. For rail transport network, freight transfer nodes in Chiang Mai, Kampaeng Phet, Saraburi, Ayudhaya, Lamphun, Khon Kaen, Nakhon Rajasima, Songkla, Surat Thani, Nakhon Sri

Dhammarat, Rajaburi, Nakhon Pathom, Laem Chabang and Rayong (especially Mabtaphut) should be made. For inland waterway transport, transfer nodes along the river Chaopraya in Ayudhaya, Pathum Thani, Nonthaburi, and Bangkok will facilitate modal shifts and transport cost reduction.

Chapter 6 Conclusions and Recommendations

An argument has been made that the traditional cost model is not best appropriate for infrastructure investment considerations and policy planning of public sector as the traditional model uses prices of transport services as inputs. The prices are costs of transport users but not the actual costs to the economy or the operational costs of transport operators. Consequently, a concept of modification of the traditional cost model is proposed that the inputs should be operational transport costs instead of prices. The transport cost components are developed from literature and redefined. Three plausible modes for transporting a container from Nakorn Luang (Ayudhaya province) to Laem Chabang Port : road, rail, and inland waterway; are examined in this thesis to determine the most economical transport mode. By using costs of transport services offered by the carriers in this route, the case study reveals that inland waterway is the most economical mode followed byrail and road. However, inland waterway has the longest transit time but road is the fastest transport mode.

The thesis presents a generalized model of transport cost definition. The cost components can be normally found in a financial statement of a company, which are: depreciation, rent, interest payments, labor costs, maintenance and repair costs, fuel costs, traffic costs, taxes, insurance costs, overhead costs, and miscellaneous costs. By changing the values of the inputs, a cost equation of a company in a micro-economic level or a transport mode in a macro-economic level can be defined. In case of Thailand, average transport costs per twenty-equivalent unit per kilometer of road, rail, and inland waterway are TB 24.33, 8, and 7.06 respectively. The route in the case study is used as a sample to construct modified cost models to observe transport activities of each transport mode namely road, rail, inland waterway, and multimodal road/rail. The result of the modified model reveals that, unlike Road, Rail and Inland waterway transport require transfer between transport modes at the transfer node, and these activities create additional costs of modal transfer. For rail transport, the costs of modal transfer include handling costs of THB 550 at the Inland Container Depot (Ladkrabang) and THB 450 at Laem Chabang Port. Inland waterway has handling costs of THB 600 at the river port (Nakorn Luang) and THB 560 at Laem Chabang Port. The reason why the cost of modal transfer of rail is lower than inland waterway is that a transfer node for rail requires lower investments on infrastructure which leads to lower handling cost per unit.

Thirdly, the traditional cost model is modified into a linear form and a new model capable for modeling intermodal competition by comparing transport cost and break-even points of each transport mode is proposed. The model is constructed based on the following cost equation:

$$TTCteu = (ATCteukm \times X) + (TCmt + TCbt)$$

To offer complete service, road transport usually does not require additional transport while rail and inland waterway require “bridging transport”, which is first-mile transport from an origin to a loading transfer node and last-mile transport from a discharging transfer node to a destination. Thus, the thesis discovers that, in case of Thailand, the cost equation of road transport is $TTC\ road = 24.33X$, the cost equation of rail is $TTC\ rail = 8X + 1000$, and the cost equation of inland waterway is $TTC\ road = 7.06X + 1160$ when assumes distance of bridging transportation is zero. However, if the distance of bridging transport is not included in the total distance, the model will be based on the following cost equation:

$$TTC\ teu \begin{cases} ACbt \times X + TCmt; 0 < X \leq a \\ ATCteu - km + Cmi; X \geq a \end{cases}$$

Fourthly, the model is constructed with various values of distance of bridging transport assumptions: 0, 20, 30, 50, and 100 kilometers. The results illustrate that when the distance of bridging transport (KM_{BT}) is none, break-even point between road and rail is 61.24 kilometers, the break-even point between road and inland waterway is 67.17 kilometers, and the break-even point between rail and inland waterway is 170.21 kilometers. In terms of intermodal competition, the result shows that road is more economical than rail for transporting goods for a distance of less than 61.24 kilometers. If the distance exceeds the break-even point of 61.24 kilometers, rail will become more economical than road. Road is more economical than inland waterway for transporting goods for a distance of less than 67.17 kilometers. When the distance exceeds the break-even point of 67.17 kilometers, inland waterway will become more economical than road. And rail is more economical than inland waterway for transporting goods for a distance of less than 170.21 kilometers. If the distance exceeds the break-even point of 170.21 kilometers, inland waterway will become more economical than rail. The break-even point between rail and inland waterway remains the same regardless of changes in the distance of bridging transport because the assumption of equal distance of bridging transport for the two modes makes both curves shift together. If the distance of bridging transport increases to 20 kilometers, the break-even point between road and rail changes to 91.03 kilometers, and the break-even point between road and inland waterway changes to 95.34 kilometers. If the distance of bridging transport is 30 kilometers, the break-even point between road and rail is 105.93 kilometers, and the break-even point between road and inland waterway is 137.61 kilometers. If the distance of bridging transport is 50 kilometers, the break-even point between road and rail is 135.73 kilometers, and the break-even point between road and inland waterway is 137.61 kilometers. And if the distance of bridging transport is 100 kilometers, the break-even point between road and rail is 210.23 kilometers, and the break-even point between road and inland waterway is 208.05 kilometers. A parameter of potential customer locations can be determined by the model as well. In case that the distance of bridging transport is symmetric, the parameter of potential market of that transfer node can be determined by dividing the total distance of the bridging transport by the number of bridging transport. And in case of asymmetric distance, the parameter can be determined by dividing the total distance of bridging transport by the known distance of the other node.

Finally, an example of how the model can be adapted to assist a decision making of locations of transfer nodes for rail and inland waterway transport is illustrated. The twenty provinces with highest nominal Gross Provincial Product in Thailand are selected as samples to analyze transport cost reductions from shifting transport mode from road to rail and inland waterway in the routes between the twenty provinces and Laem Chabang and Bangkok. The model suggests that there will be reductions of more than 20% of transport costs if freight transport is shifted from road to rail in the routes between Laem Chabang Port and these provinces: Ayudhaya , Saraburi, Khon Kaen, Nakhon Rajasima, Songkla, Nakhon Pathom, Chiang Mai, Nakhon Sri Dhammarat, Surat Thani, Rajaburi, Khampaeng Phet, and Lamphun and between Bangkok and the following provinces: Rayong, Khon Kaen, Nakhon Rajasima, Songkla, Chiang Mai, Nakhon Sri Dhammarat, Surat Thani, Rajaburi, Kamphaeng Phet, and Lamphun. Shifting freight transport mode from road to inland waterway also presents cost reductions in the route between Laem Chabang Port and Ayudhaya, Pathum Thani, Nonthaburi, Bangkok, and Samut Sakhon. Rail transport can access to more extended hinterland than inland waterway because geographical restriction of the inland waterway i.e. availability of navigable channels and draft restrictions of the major rivers in Thailand. A recommendation on infrastructure development policy based on this example of the application of the model is that it is beneficial to the country’s economy in terms of transport cost saving if investment and development of rail transport is made in the following lines: the North Line from Bangkok to Chiang Mai with freight transfer nodes in Chiang Mai, Kampaeng Phet, Saraburi, Ayudhaya, and Lamphun; the North East Line at least from Bangkok to Khon Kaen with transfer nodes in Khon Kaen and Nakhon Rajasima; the South Line with transfer nodes in Songkla, Surat Thani, Nakhon Sri Dhammarat, Rajaburi, and Nakhon Pathom. And finally the East Line with transfer nodes in Laem Chabang and Rayong (especially Mabtaphut). Although the model suggests that there are transport cost reductions if freight transport between Laem Chabang Port and Ayudhaya, Pathum Thani, Nonthaburi, Bangkok, and Samut Sakhon is shifted from road to rail, unlike the rail transport, inland waterway transport is performed mostly by private sector. As a result, the policy on modal shift of freight transport from road to inland waterway mainly concerns with promotion and facilitation.

Shifting freight means road transport will be used in bridging services between transfer nodes and origins and destinations, this will help reduce average haulage distance of road carriers. The reduction of average road haulage distance will be beneficial because it also decrease possibility and distance of ballast haul. Consequently, the modal shifts of freight transport from road to rail and inland waterway do not only benefit environment in terms of less pollution per unit transported and rail and inland waterway in terms of increased cargo volume, but the modal shifts also promote greater efficiency of road transport as well.

Another recommendation from this thesis is that although rail and inland waterway transport have longer transit time than road, the arriving and departing cargoes (containers) have lower variance than that of road. As a result, an extended gate concept is an interesting and beneficial concept that can be adapted and applied to rail and inland transport to compensate their disadvantage of longer transit time.

Chapter 7 Limitations and Future Research

The first limitation is the cost equations in this thesis are linear because they are based on an assumption that returns to scale in transport operations are constant. The second limitation is the average cost per kilometer of rail transport is based on data stated by the State Railway of Thailand, but not an actual calculation as the average transport cost of road and inland waterway because the financial statement of the SRT does not distinguish between passenger and freight operations. The third limitation of this thesis is the operational costs of road and inland waterway transport are derived from a single company in each mode. For inland waterway transport this might not be a significant issue as there are only few operators offering the services, and in case of container transport there is only one company who is currently offering the service. On the other hands, road carriers are numerous and there are many operators offering similar services in the same route. However, the data and information on operational costs is considered as confidential and operators are usually reluctant to disclose their cost figures. Finally, the proposed model considers only cost perspective, but not others especially transit time.

The limitations leave rooms for future research. The returns to scale of each transport mode can be scrutinized whether they are constant. A further study on transport costs especially the operational costs of rail transport to identify values of cost components proposed in this thesis. With the completed cost components, the model can be developed further to reflect the reality when other factors such as fuel prices or charges changes. The cost difference or reductions found by the model can also be used as an input in a modal choice model to determine whether the transport cost saving from the modal shifts effects the decision on transport mode of shippers of a particular product.

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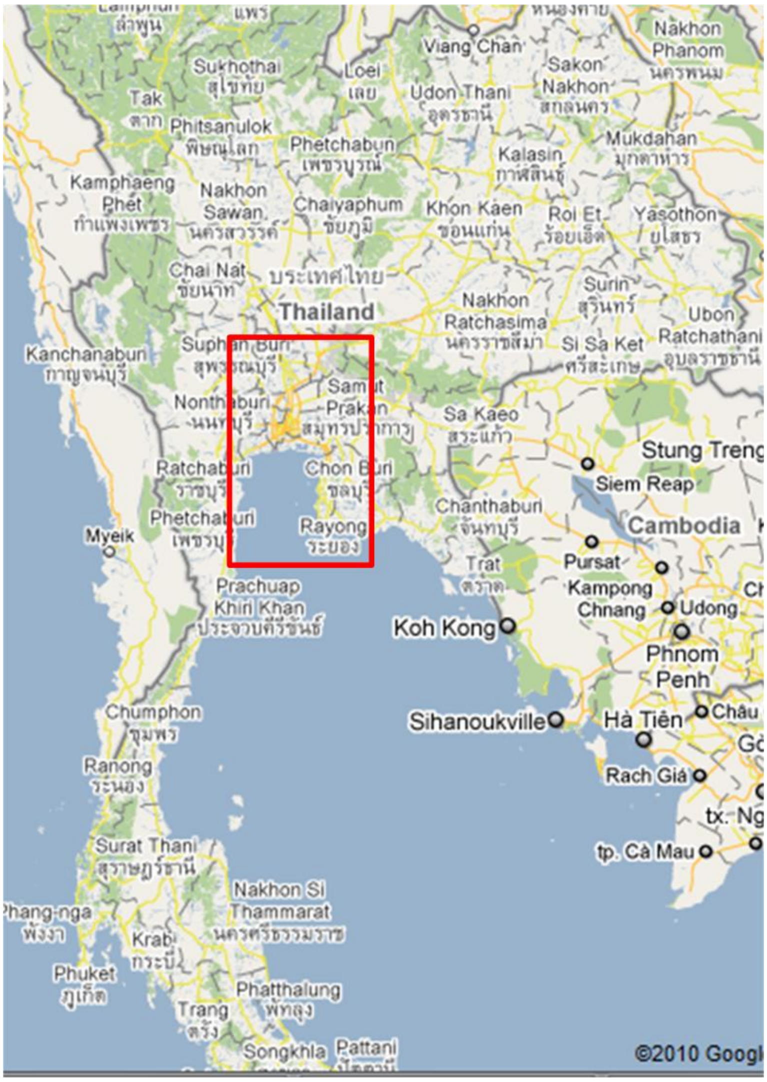
Appendices

Appendix I Map of Thailand

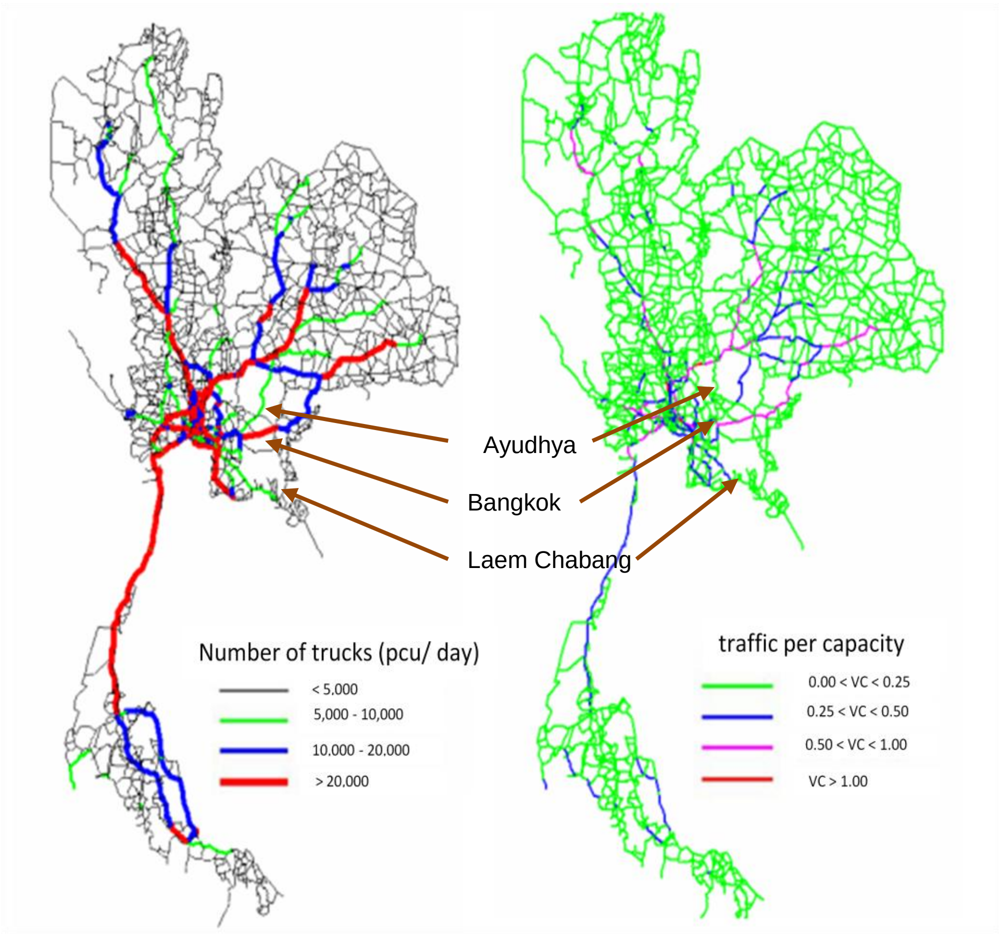


Source: adapted from GoogleMaps (2010)

Appendix II Important locations in the case study

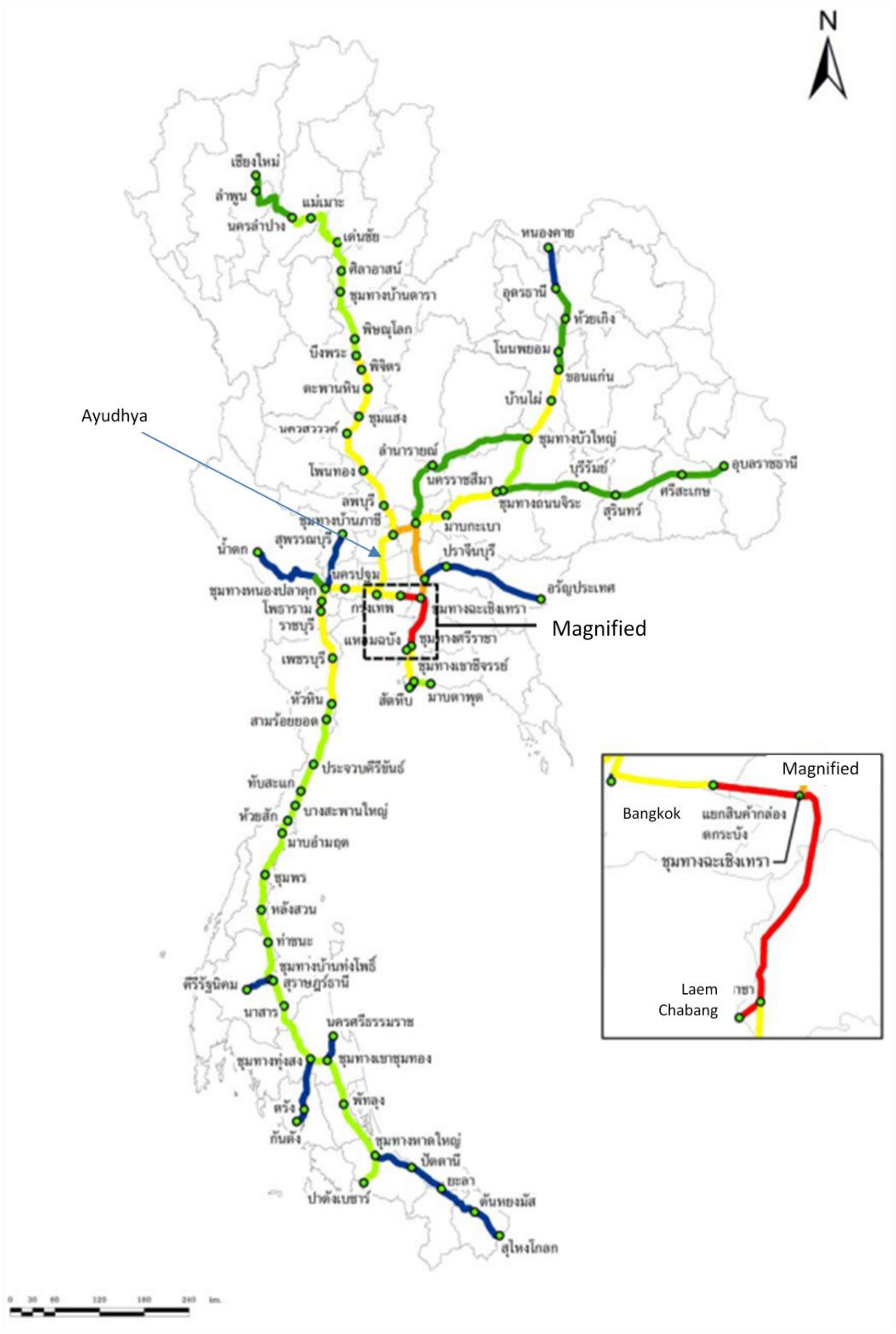
Source: adapted from GoogleMaps (2010)

Appendix III Utilization of Thailand’s Highway Network in 2005



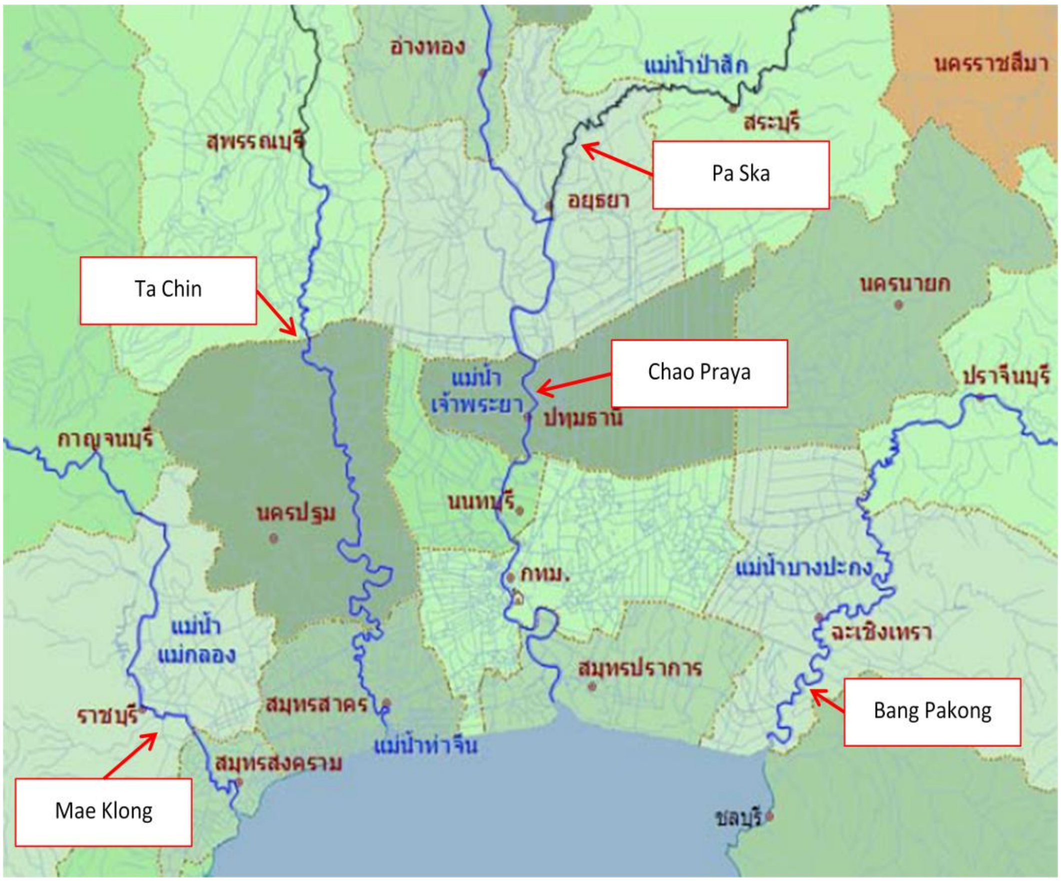
Source: adapted from Ministry of transport (2006a)

Appendix IV Utilization of Thailand’s Railway Network in 2005



Source: Ministry of Transport (2006a)

Appendix IV Five major rivers in Thailand



Source: adapted from Ministry of Transport (2006a)

Appendix VI Existing Industrial Estates in Thailand 2008

Source: Industrial Estate Authority of Thailand (2008)