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Measurement of energy-saving effect by intermodal freight transport in Thailand

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Abstract: In Thailand, transport sector is the largest energy consuming sector (38%). Road haulage of freight transport accounts for approximately 92% of total domestic freight movements. Accordingly, it is one of the largest contributors to adverse environmental impacts. This study presents one option to reduce energy consumption through modal shift from trailer to intermodal transport involving railway and waterway. It focuses on freight movements between Bangkok and Hat Yai in Thailand. Energy savings are measured by multi-objective optimisation model using decision variables consisting of three mode options: trailer only, intermodal-rail and intermodal-waterway. In addition to energy consumption, the objective function also includes time and charge of shipment factor.

Keywords: intermodal transport; energy consumption; multi-objective optimisation model.

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1 Introduction

Domestic freight movement in Thailand in 2005, calculated on the basis of tonnage, was proportioned as 92.8% by road, 5.1% by waterway (river and coastal), 2.1% by rail and 0.01% by air (MOT, 2005). The prevalence of road transport resulted in various problems, such as traffic congestion, noise, vibration, and emissions of NO_x and CO_2. The transport sector is the most energy-consuming sector (38.3%) in Thailand (EPPO, 2006), and almost 80% of energy consumption in this sector is used for land transport, where 78.6% of energy is consumed by cars and trucks and only 0.5% of energy is consumed by rail. Waterway transport accounts for only 4.6% of the total consumption, and the remaining 16.3% is associated with air transport (EPPO, 2003).

Road haulage is the most energy-consuming mode of freight transport, compared with transport by rail or water, in terms of energy efficiency per ton-km. The energy consumed for the shipment of goods by rail or barge is substantially less than that consumed by truck. For instance, in the USA, the energy consumption of truck transport, in terms of joule per ton-km, is approximately 12 times higher than that of rail or waterway transport (IEA, 2001). Shinke et al. (2007) quantified the reduction of CO_2 emission resulting from a shift from truck to rail and waterway transport in Japan. It was revealed that under these circumstances, CO_2 emission was reduced by 2.8% for rail transport and by 1.8% for waterway transport. However, studies to date neglect other important factors such as the transport time and the shipment charge when estimating energy saving. Despite the recent emphasis on making transport more environmentally friendly, little research has examined the relation between logistical structure and the choice of mode of transport (McKinnon, 1999). To examine energy saving in intermodal transport, we should consider this problem from a multi-objective point of view. There have been no relevant studies on intermodal transport in Thailand except by Kunadhamraks and Hanaoka (2008), who developed a method for evaluating its performance.

The objectives of this study are

- to develop an optimisation model for estimating the modal share in the context of a multi-objective optimisation problem
- to measure consequences for energy saving by comparing an estimated modal share with the actual modal share.

To measure energy saving, energy consumption in modes of transport with different degrees of energy efficiency, such as trailer, rail and waterway transport, must be analysed in terms of identical Origin and Destination (OD) and cargo volume parameters. This study focuses on the route between Bangkok and Hat Yai, where trailer-only, rail-intermodal and waterway-intermodal transport are available. In general, the logistics companies (e.g. freight forwarders) do not consider energy consumption as a criterion for the choice of transport mode. Thus, the optimal modal share is determined here using a multi-objective optimisation model to minimise energy consumption, transport time and shipment charge.

2 Model

2.1 Formulation of the multi-objective optimisation problem

Logistics companies were queried to determine which factor among transport time, shipment charge, security and reliability was considered to be the most important factor for choosing a particular mode of transport (details are given in Section 3). The shipment charge and the transport time were identified as the two most important factors. The model in this study is formulated as a multi-objective optimisation problem with the following three variables: energy consumption, transport time and shipment charge. Therefore, the model has three objective functions – minimising the total energy consumption, the total transport time and the total shipment charge – for a given cargo volume from the origin to the destination.

The optimisation model developed here was inspired by earlier work, in particular IEE (1993), Greene and Fan (1994) and Schipper et al. (1997), which focused on energy consumption for the movement of a given cargo volume in terms of ton-km. The optimisation model is formulated as follows:

$$\min f_1 = \sum_j \sum_k \mu_{jk} \times s_j \times d_{jk} \times W \times \alpha_{jk} \times \beta_{jk} \tag{1}$$

$$\min f_2 = \sum_j \sum_k \frac{d_{jk}}{v_{jk}} \times s_j \times W \times \sigma_{jk} \times \rho_{jk} + \sum_j \sum_{k-1} D_{jk,j(k+1)} \times s_j \times W \tag{2}$$

$$\min f_3 = \sum_j \sum_k c_{jk} \times s_j \times d_{jk} \times W + \sum_j \sum_{k-1} C_{jk,j(k+1)} \times s_j \times W \tag{3}$$

s.t.

$$\sum_j s_j = 1 \tag{4}$$

$$s_j \geq 0 \quad \forall j \tag{5}$$

where

f_1: Total energy consumption (BTU)
f_2: Total transport time (ton-h)
f_3: Total shipment charge (Baht)
j: Route
k: Transport mode
μ_{jk}: Energy efficiency (BTU/ton-km)
v_{jk}: Travel speed (km/h)
c_{jk}: Unit shipment charge (Baht/ton-km)
d_{jk}: Distance travelled (km)
W: Total cargo volume (ton)
α_{jk}: Energy consumption adjustment factor for load
β_{jk}: Energy consumption adjustment factor for Empty Haulage

σ_{jk}: Transport time adjustment factor for load

ρ_{jk}: Transport time adjustment factor for Empty Haulage

$D_{jk,j(k+1)}$: Transhipment time at seaport(s)/rail terminal(s) (h)

$C_{jk,j(k+1)}$: Shipment charge at seaport(s)/rail terminal(s) (Baht/ton)

s_j: Modal share of route *j*.

2.2 Objective functions

The first objective function is to minimise the total energy consumption (f_1) for the shipment of a given cargo volume from its origin to its destination along different routes. Only energy consumption for shipment by the actual transport modes is considered here, ignoring other contributions to energy consumption at seaports or rail terminals associated with handling, loading and relocations of containers owing to the limitation of data availability. The total energy consumption is measured in British Thermal Units (BTU). The second objective function is to minimise the total transport time (f_2) for a particular mode. Transhipment time at seaports or rail terminals is also considered. The total transport time is the summation of the shipment time and the transhipment time through different modes k and $(k + 1)$. The unit of total transport time is the ton-h, which allows the transport time to be measured in terms of the unit ton. The third objective function is to minimise the total shipment charge (f_3) for the shipment of a given cargo volume from one origin to one destination by different routes. It includes the tariff/charge incurred at seaports or rail terminals and is measured in Thai Baht (1 USD = 35.18 Baht, as of January 2009).

2.3 Input parameters

2.3.1 Energy efficiency (μ_{jk})

The energy efficiency is estimated for each mode on the basis of the energy used per ton-km of freight carried. This is done by estimating the energy used and dividing it by the tonnage carried times the distance covered in kilometres (DOE, 1982). In this study, the energy efficiency of a particular mode is given by

$$\mu_{jk} = \frac{139,000}{3.7854 \times e_{jk} \times V_{jk}}, \tag{6}$$

where

μ_{jk}: Energy efficiency (BTU/ton-km)

e_{jk}: Fuel efficiency (km/litre)

V_{jk}: Average shipment volume (ton)

1 gallon (US) = 3.7854 l, 1 gallon of diesel = 139,000 BTU.

2.3.2 Travel speed (v_{jk})

The travel speed can be defined as the distance travelled by a particular mode over a unit length of time. In this study, the travel speed by different types of modes is given by

$$v_{jk} = \frac{d_{jk}}{t_{jk}} \tag{7}$$

where

v_{jk}: Travel speed (km/h)

d_{jk}: Distance travelled (km)

t_{jk}: Transport time (h).

2.3.3 Unit shipment charge (c_{jk})

The shipment charge is the charge paid by clients to logistics companies for the shipment of a given cargo volume from its origin to its destination. The unit shipment charge is calculated as the shipment charge divided by the tonnage carried times the distance covered in kilometres, as expressed in equation (8). In Thailand, it is widely known that the depreciation cost of an automobile, which may include a trailer, is low, and this is also true for rolling stock and barges, which can be used for 30–40 years on average. Thus, in this study, the fixed cost for each haulage is ignored.

$$c_{jk} = \frac{B_{jk}}{d_{jk}} \tag{8}$$

where

c_{jk}: Unit shipment charge (Baht/ton-km)

B_{jk}: Shipment charge (Baht/ton)

d_{jk}: Distance travelled (km).

2.3.4 Energy consumption adjustment factor for load (α_{jk})

Even in the same transport mode, energy consumption depends on the loading conditions. In this study, the Load Factor (LF) and Empty Haulage (EH) are taken into account for assessing the impact of energy consumption on the results. The LF is one of the measures for the operating efficiency, which is used in logistics to determine the utilised capacity percentage (equation (9)). It is the ratio of the average load to the total vehicle freight capacity, expressed in tones or volume. Energy consumption and, consequently, energy efficiency vary with the LF. Thus, it is necessary to determine the adjustment factor to measure the energy efficiency more accurately.

$$LF = \frac{V_{jk}}{M_{jk}}, \tag{9}$$

where

LF: Load Factor (%)

M_{jk}: Loading capacity of freight (ton).

Fuel efficiency (e_{jk}) is approximately proportional to the weight of the vehicle (NHTSA, 2003). This means that the weight is one of the most significant variables that determine fuel efficiency. On the basis of this concept, the energy efficiency (μ_{jk}) of different LF can be determined by considering a linear relationship between fuel efficiency (km/l) and the LF. In case, the LF is 100%, the energy consumption adjustment factor would be 1.0. The energy consumption adjustment factor is defined in equation (10). As the LF decreases, the energy efficiency also decreases. Adjustment factors are determined for each type of transport mode.

$$\alpha_{jk} = \frac{\mu_{jk}^{\text{any}}}{\mu_{jk}^{\text{full}}} \tag{10}$$

where

α_{jk}: Energy consumption adjustment factor for load

μ_{jk}^{any}: Energy efficiency at any load (BTU/ton-km)

μ_{jk}^{full}: Energy efficiency at full load (BTU/ton-km).

2.3.5 Energy adjustment factor for Empty Haulage (β_{jk})

EH is equivalent to the case where the LF is 0, which is normally a consequence of an unbalanced supply and demand relationship. As the number of EH increases, the energy efficiency per ton-km decreases. Thus, the proportion of EH is used as another adjustment factor. EH can be defined as the percentage of times that a vehicle returns with an empty cargo between OD. In this study, the proportion of EH was calculated using the concept outlined in Figure 1 and equation (11). An EH of 100% means the vehicle returned empty every time. In short, EH equals 1.0 when, for a given round trip, the vehicle is empty on the return journey. Similarly, EH equals 0.5 when the vehicle is empty on only one return journey for two round trips.

$$\text{EH} = \frac{N_{jk}^{re}}{N_{jk}^{\text{round}}} \times 100 \tag{11}$$

where

EH: Empty Haulage (%)

N_{jk}^{re}: Number of EH on return haulage (times)

N_{jk}^{round}: Number of round trip between OD (times).

Equation (12) determines the energy consumption adjustment factor for EH by considering the fuel efficiencies (km/l) of a Full Container Load (FCL) and for an empty load. Thus, β_{jk} is 1.0 when EH is 0%. The function $\beta_{jk,}$ formulated as energy efficiency, becomes lower when EH increases.

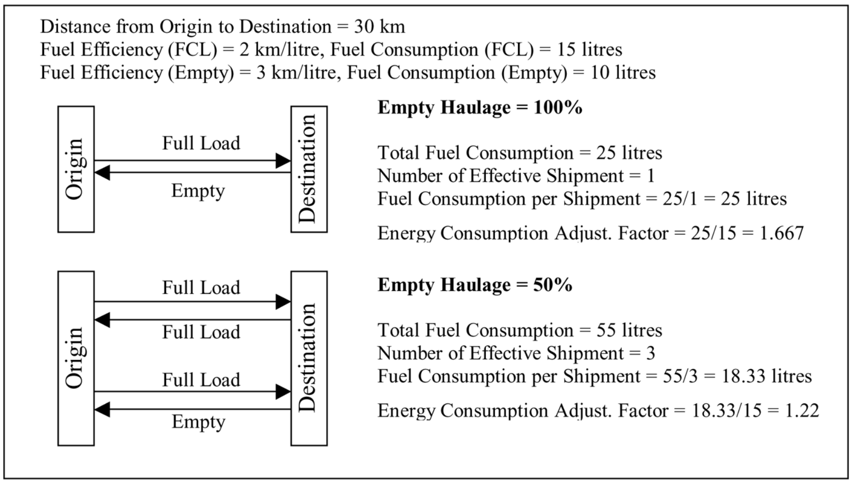
$$\beta_{jk} = 1 + \frac{\mu_{jk}^{\text{full}}}{\mu_{jk}^{\text{empty}}} \times \frac{\text{EH}/2}{100 - (\text{EH}/2)}, \tag{12}$$

where

β_{jk}: Energy consumption adjustment factor for Empty Haulage

μ_{jk}^{empty}: Fuel efficiency at any load (BTU/ton-km).

Figure 1 How to calculate Empty Haulage



Distance from Origin to Destination = 30 km

Fuel Efficiency (FCL) = 2 km/litre, Fuel Consumption (FCL) = 15 litres

Fuel Efficiency (Empty) = 3 km/litre, Fuel Consumption (Empty) = 10 litres

Empty Haulage = 100%

Total Fuel Consumption = 25 litres

Number of Effective Shipment = 1

Fuel Consumption per Shipment = 25/1 = 25 litres

Energy Consumption Adjust. Factor = 25/15 = 1.667

Empty Haulage = 50%

Total Fuel Consumption = 55 litres

Number of Effective Shipment = 3

Fuel Consumption per Shipment = 55/3 = 18.33 litres

Energy Consumption Adjust. Factor = 18.33/15 = 1.22

2.3.6 *Transport time adjustment factor for load (σ_{jk}) and Empty Haulage (ρ_{jk})*

The travel speed of a vehicle is also affected by volume of its cargo. In other words, transport time also varies with the LF. Since an empty trailer and a trailer with LF less than 1.0 is more likely to move faster than a trailer with FCL, the adjustment factor for the load becomes necessary to obtain a more accurate transport time. Thus, in this study, it is assumed that the travel speed of a trailer in the condition of EH is 20% faster compared with FCL. Similarly, rail and waterway vehicles are 10% faster than those under FCL condition. Then, the transport time adjustment factor is determined by the assumption that the change in the travel speed of each mode is proportional to the cargo weight.

2.3.7 *Transhipment time at seaport(s)/rail terminal(s) ($D_{jk,j(k+1)}$)*

In the case of intermodal transport, the transhipment time for handling, storage, stuffing and relocation of the containers at seaports or rail terminals must be considered. In this study, $D_{jk,j(k+1)}$ indicates the transhipment time incurred for transferring the container at the point of interchange between the modes k and $k + 1$ on route j. This is measured by the hour.

2.3.8 *Shipment charge at seaport(s)/rail terminal(s) ($C_{jk,\,j(k+1)}$)*

The shipment charge at seaports and rail terminals depends on many factors and differs from one seaport or rail terminal to the next. A tariff can be charged either per container (20′, 40′ or 45′) or per ton of freight. Import and export shipment charges are also different. For the purpose of maintaining the consistency of the objective functions, shipment charge at seaports and rail terminals includes only handling charge in Baht/ton. $C_{jk,j(k+1)}$ represents the shipment charge incurred for transferring the container at the point of interchange between the modes k and $k + 1$ on route j. Although, in general, additional costs of labour and inventory will be required for longer transhipment times, for example as a result of a delay, this is not considered in this study.

2.4 Constraints

Two constraints are incorporated within the objective functions. The first constraint (equation (4)) is used to ensure that the sum of modal shares via different routes must always be equal to one. The second constraint (equation (5)) is used for sign restriction to ensure non-negative values for all modal shares.

2.5 Output (s_j)

The output of the model gives Pareto-optimal solutions for the modal shares. This paper also focuses on the effectiveness of energy saving of each Pareto-optimal solution, which cannot be better off without making some other value worse off (Collette and Siarry, 2003). The s_j indicates the optimal modal share for route j.

Optimisation is done with WWW-NIMBUS, a Non-differentiable Interactive Multi-objective Bundle-based optimisation System (Miettinen and Mäkelä, 1999, 2006). With this interactive web-based software, the user can define the problem to be solved and set preferences in a flexible way, by changing the beginning and end conditions to generate a number of optimal solutions. Results are generated by a local solver using a proximal bundle method and global solvers using Genetic Algorithms (GAs). The structure of the interactive NIMBUS algorithm does not limit the variety of its applications in the area of multi-objective optimisation. An implementation WWW-NIMBUS (Miettinen and Mäkelä, 2000) of the NIMBUS method is available on the internet at http://nimbus.mit.jyu.fi/. WWW-NIMBUS contains two variant GAs with different constraint-handling techniques (Miettinen et al., 2003). One of these techniques is based on adaptive penalties, and the other technique can be called a method of parameter-free penalties.

3 Numerical results

3.1 Data collection and parameter setting

A questionnaire survey was conducted to investigate preferences and behaviours of different types of logistics companies in Thailand related to domestic freight transport. These companies included freight forwarders, transport operators and shippers. The questionnaire (in Thai language) was distributed to 300 container cargo companies located in the vicinity of Bangkok, close to Laem Chabang Port and Lat KraBang Inland Container Depot (ICD) in the Bangkok suburbs. This is the only area where intermodal transport is actively used in Thailand.[1] The survey was carried out by a number of methods, including face-to-face interviews, telephone interviews, postal delivery, fax and e-mail in the period between December 2005 and January 2006. Most of the data were obtained by face-to-face and telephone interviews. Other communication methods (postal delivery, fax and e-mail) yielded much fewer respondents. From 300 sets of distributed questionnaire, 137 sets were returned, from which 110 (48 shippers, 32 carriers and 30 freight forwarders) were selected by filtering out incomplete and unreliable sets. Most of the non-respondents had been sent the questionnaires by post, fax and e-mail. On the other hand, the face-to-face and telephone interviews generally gave a high response rate. However, the type of respondents has no relationships with the number of non-respondents.

The questionnaire consisted of questions regarding the cargo volume for each transport mode, the significant factor for choosing a particular transport mode, the frequency of use for each type of trailer (6 wheels, 8–10 wheels and 18 wheels), the proportion of EH of a trailer, the fuel efficiency for each type of trailer, the distribution pattern of representative transport modes (either using intermodal transport or not), the travel speed of haulage, and the transhipment time and shipment charge at the seaports and rail terminals. For the purpose of checking the reliability of the data, an additional questionnaire survey was conducted with another set of companies, which resulted in 62 valid samples. A *t*-test was performed between the first 110 samples and second set of 62 samples with a significance threshold of 5% (two-tailed). There was no significant difference between the sample populations, which confirms the stability of the data. The questionnaires showed the modal share for the logistics companies interviewed distributed as 77.3% for trailer, 13.9% for rail and 8.8% for waterway transport, in terms of metric tons. Rail transport had a much higher modal share in the area studied than in the whole of Thailand. The weighted average of EH for trailers was 47.4% (shipper 51.0%, carrier 45.9% and freight forwarder 43.1%).

3.2 Case study: Route between Bangkok and Hat Yai in Thailand

A case study of the route from Bangkok to Hat Yai was carried out to estimate the impact of intermodal transport on energy saving. Figure 2 shows a map of southern Thailand, which includes Bangkok and Hat Yai. Within this network, three transport modes are available: trailer-only (Route 1), intermodal-rail (Route 2) and intermodal-waterway (Route 3). On the basis of the questionnaire survey, the maximum load for 6- and 18-wheel trailers are 10.60 tons and 36.40 tons, respectively. These three routes are shown in Figure 3 as a route network. According to the interview survey to the Ministry of Transport (MOT) of Thailand, the actual modal share for 2008 on this route was 94.8% for trailers, 4.7% for coastal shipping, 0.3% for rail and 0.2% for air transport. Types of the commodity are mainly rice, fish and vegetable, which are classified as class 4 (MOT, 2006). Containers may be used for transporting rice and vegetables, but not for fish. On this route, several products other than rice, vegetable and fish are transported, such as sugar and rubber. The unit shipment charge for rail is determined by assuming the transport of class-4 products for convenience.

Parameter values for energy efficiency, the energy consumption adjustment factor, travel speed and transhipment time at seaport and rail terminal are derived from the questionnaire survey, whereas other parameters are set from the interview survey and literature-based survey results (MOT, 2001; PDP Australia Pty Ltd/Meyrick and Associates, 2005; SRT, 2004). The data set is summarised in Table 1.

Table 1 Data sets of parameters for the calculation

Route 1: Trailer-only	
Cargo volume	=200 ton
Energy efficiency	=480.25 BTU/ton-km
Distance	=926 km
Energy consumption adjust. Factor (load)	=1.45
Energy consumption adjust. Factor (EH)	=1.23
Travel speed	=43.60 km/h
Transport time adjust. Factor (load)	=0.93
Transport time adjust. Factor (EH)	=1.28
Unit shipment charge	=0.93 Baht/ton-km
Route 2: Intermodal-rail	
Cargo volume	=200 ton
Energy efficiency (trailer)	=1,106.76 BTU/ton-km
Distance (trailer)	=27 km
Energy consumption adjust. Factor (trailer, load)	=1.25
Energy consumption adjust. Factor (trailer, EH)	=1.23
Energy consumption adjust. Factor (rail, load)	=1.09
Energy consumption adjust. Factor (rail, EH)	=1.05
Energy efficiency (rail)	=650 BTU/ton-km
Distance (rail)	=945 km
Travel speed (trailer)	=41.1 km/h
Transport time adjust. Factor (trailer, LF)	=0.94
Transport time adjust. Factor (trailer, EH)	=1.28
Transport time adjust. Factor (rail, LF)	=0.96
Transport time adjust. Factor (rail, EH)	=1.03
Travel speed (rail)	=59.51 km/h
Transhipment time (rail terminal)	=20 h
Unit shipment charge (trailer)	=5.04 Baht/ton-km
Unit shipment charge (rail)	=0.46 Baht/ton-km
Shipment charge (rail terminal)	=(45 + 50) Baht/ton
Route 3: Intermodal-waterway	
Cargo Volume	=200 ton
Energy efficiency (trailer)	=1,106.76 BTU/ton-km
Distance (trailer)	=7 + 35 km
Energy consumption adjust. Factor (trailer, load)	=1.25
Energy consumption adjust. Factor (trailer, EH)	=1.23
Energy consumption adjust. Factor (barge, load)	=1.43
Energy consumption adjust. Factor (barge, EH)	=1.17
Energy efficiency (barge)	=260 BTU/ton-km

Table 1 Data sets of parameters for the calculation (continued)

Route 3: Intermodal-waterway	
Distance (barge)	=798 km
Travel speed (trailer)	=41.1 km/h
Transport time adjust. Factor (trailer, load)	=0.94
Transport time adjust. Factor (trailer, EH)	=1.28
Transport time adjust. Factor (barge, Load)	=0.95
Transport time adjust. Factor (barge, EH)	=1.17
Travel speed (barge)	=25.37 km/h
Transhipment time (seaport)	=12 h
Unit shipment charge (trailer)	=5.04 Baht/ton-km
Unit shipment charge (barge)	=0.44 Baht/ton-km
Shipment charge (seaport)	=(77 + 68) Baht/ton

Substituting parameters for objective function

$$\begin{aligned} f_1 = {} & 480.25 * 926 * 1.45 * 1.23 * 200 * s_1 \\ & + (1{,}106.76 * 27 * 1.25 * 1.23 + 650 * 945 * 1.09 * 1.05) * 200 * s_2 \\ & + (1{,}106.76 * (7 + 35) * 1.25 * 1.23 + 260 * 798 * 1.43 * 1.17) * 200 * s_3 \end{aligned}$$

$$\begin{aligned} f_2 = {} & 926/43.6 * 0.93 * 1.28 * 200 * s_1 \\ & + (27/41.1 * 0.94 * 1.28 * 945/59.51 * 0.96 * 1.03 + 2 * 20) * 200 * s_2 \\ & + ((7 + 35)/41.1 * 0.94 * 1.28 * 2 + 798/25.37 * 0.95 * 1.17 + 2 * 12) * 200 * s_3 \end{aligned}$$

$$\begin{aligned} f_3 = {} & 0.93 * 926 * 200 * s_1 \\ & + (5.04 * 27 + 0.46 * 945 + 45 + 50) * 200 * s_2 \\ & + (5.04 * (7 + 35) + 0.44 * 798 + 77 + 68) * 200 * s_3 \end{aligned}$$

Figure 2 Southern part of Thailand including Bangkok and Hat Yai

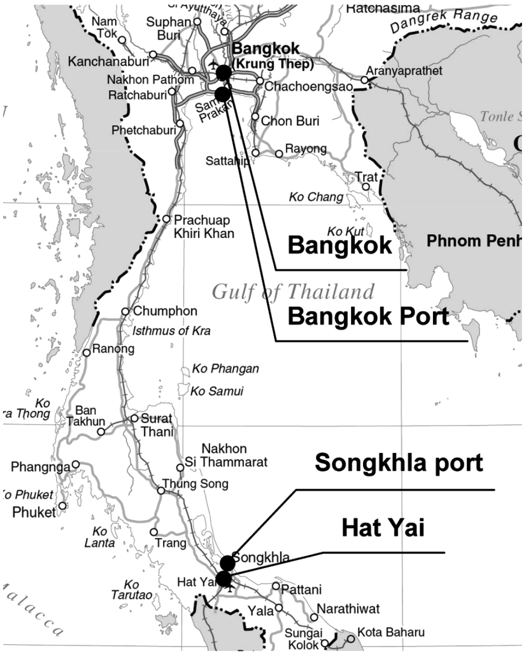
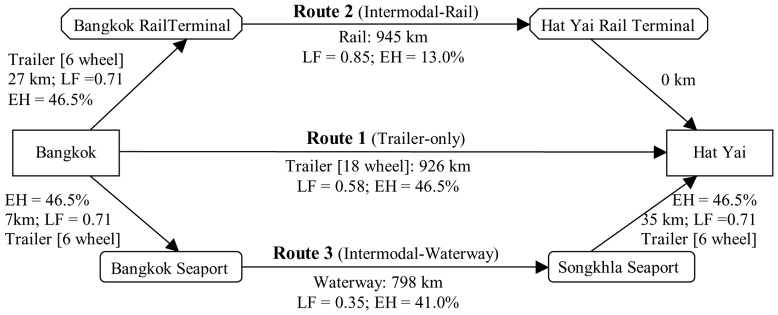


Figure 3 Route network between Bangkok and Hat Yai



On the basis of the interview survey, the 18-wheel trailer was selected for route 1 with the trailer-only case, whereas the 6-wheel trailer was used for intermodal-rail and intermodal-waterways by means of the access and egress transport mode of both intermodal-rail and intermodal-waterway. The distance between Hat Yai railway terminal and the city centre of Hat Yai is very short (0.2 km) and was assumed to be 0 km for convenience. The analysis considered the shipment of 200 tons from Bangkok to Hat Yai. The LF and EH of the trailers were set on the basis of the interview survey.

The data in Table 1 were input in WWW-NIMBUS to generate Pareto optimal solutions for the modal share transported by routes 1–3. WWW-NIMBUS performs the optimisation by giving priority to a particular objective function. In this study, the minimisation of energy consumption was given priority. Pareto-optimal solutions ranging from the base solution (alternative 1) to the solution for minimum energy consumption (alternative 8) are summarised in Table 2.[2] The base solution here represents the "solution that is at the median between the maximum and the minimum value among the Pareto-optimal solutions which can be generated".

Table 2 Pareto-optimal solutions for energy minimisation

	Modal Share (%)			*Objective functions*		
Alternatives	*Route 1* (s_1)	*Route 2* (s_2)	*Route 3* (s_3)	*Energy* (BTU × 10^6)	*Time* (ton-h × 10^3)	*Charge* (Baht × 10^3)
1 (base)	44.98	10.61	44.41	124.54	8.69	154.40
2	38.55	9.10	52.35	118.76	9.13	152.54
3	32.13	7.58	60.29	112.97	9.56	150.68
4	25.70	6.06	68.24	107.19	10.00	148.83
5	19.28	4.55	76.17	101.41	10.43	146.97
6	12.85	3.03	84.12	95.62	10.87	145.11
7	6.43	1.52	92.05	89.84	11.30	143.26
8	0	0	100	84.06	11.74	141.40

As for the change of alternative solutions, transport time would increase and shipment charge would decrease as energy consumption is reduced. On the other hand, there is a trade-off between energy consumption and transport time; the shipment charge is proportional to energy consumption. To minimise energy consumption, the transport time should be increased. The modal share of the basic solution was calculated as follows: trailer-only (route 1) 45%, intermodal-rail (route 2) 11% and intermodal-water (route 3) 44%, respectively. The actual modal share for a trailer in 2008 was 94.8% as mentioned before. This study compares the actual modal share[3] with each Pareto-optimal solution for the purpose of assessing the effectiveness of energy savings and the corresponding value of other objective functions. This is summarised in Table 3.

Table 3 Comparison with actual modal share

Alternatives	*Energy* (BTU × 10^6)	*Change* (%)	*Time* (ton-h × 10^3)	*Change* (%)	*Charge* (Baht × 10^3)	*Change* (%)
1 (base)	124.54	–25.64	8.69	37.74	154.40	–17.56
2	118.76	–29.10	9.13	44.72	152.54	–18.55
3	112.97	–32.55	9.56	51.53	150.68	–19.54
4	107.19	–36.00	10.00	58.51	148.83	–20.53
5	101.41	–39.45	10.43	65.32	146.97	–21.53
6	95.62	–42.91	10.87	72.30	145.11	–22.52
7	89.84	–46.36	11.30	79.11	143.26	–23.51
8	84.06	–49.81	11.74	86.09	141.40	–24.50

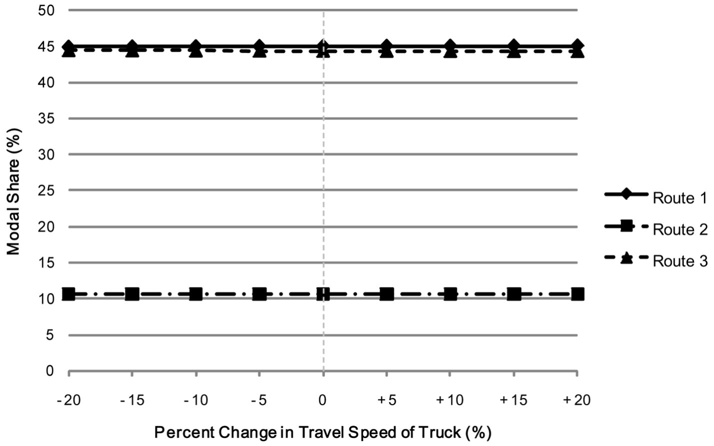
It is shown that a 25% reduction of energy consumption can be achieved by utilising intermodal transport in the base case. For the alternative solutions, energy consumption is considerably reduced by the increase in the modal share of intermodal-waterway transport. From these results, it can be concluded that modal shift from trailer to intermodal transport is quite effective in reducing energy consumption. However, alternative 8, which is a solution for minimum energy consumption, leads to a 100% share for intermodal-waterway transport. This means that intermodal-waterway transport is preferable for minimising energy consumption; however, it is not a viable solution. In Table 3, the transport time, which shows a trade-off with energy consumption, is 37% longer compared with the actual modal share in the base case and also in other alternatives. Although intermodal transport is quite effective in reducing energy consumption, it should be treated as a trade-off relation. The sensitivity of transport time is relatively significant against energy consumption, whereas of shipment charge is relatively small. It is, therefore, important to take into account the transport time in minimising energy consumption.

3.3 Sensitivity analysis

Several parameters that were used as input for the model were assigned values as realistic as possible. Nevertheless, results of calculation are affected by the scale of numerical values. Thus, in this study, sensitivity analysis was conducted for observing the modal share as a result of changing three parameters, such as the travel speed of a trailer, the shipment charge at a seaport, and the transhipment time at a seaport to assess the reliability of the calculation. This analysis was done for the base case (alternative 1).

The sensitivity to change in the travel speed of a trailer is shown in Figure 4. The horizontal and vertical axes indicate the percentage change in travel speed of a trailer and the modal share of each route, respectively. As the travel speed is decreased, a slight reduction of the modal share on route 1 (truck only) is observed. However, there is only a small decrease of 0.103% in the modal share over route 1 for a 20% decrease in trailer travel speed. Thus, modal share is not significantly affected by the change in trailer travel speed.

Figure 4 Change in each modal share by change in travel speed of trailer



With regard to the shipment charge at seaports, the sensitivity of the modal share for each route was analysed over a wider range of values from –50% to +50%. Results are shown in Figure 5. The sensitivity for intermodal-rail transport (route 2) is higher than for other modes (routes 1 and 3). The modal share for route 2 is 18.16% (a +7.55% increase) for a 50% increase in the shipment charge at seaports. On the other hand, the modal share for route 2 reaches almost 0% for a 30% reduction. Subsequently, the fluctuation of the seaport charge has an effect on the modal share of rail-intermodal transport. Nevertheless, the order of the modal share for each route is not changed at all within the range of values in the analysis.

Figure 5 Change in each modal share by change in shipment charge at seaport

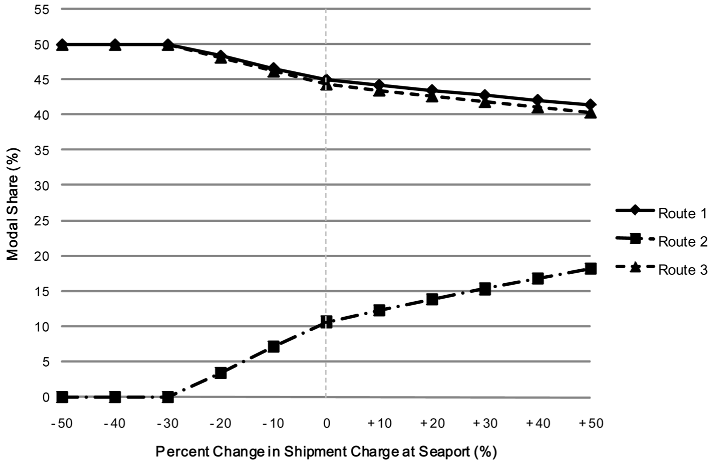
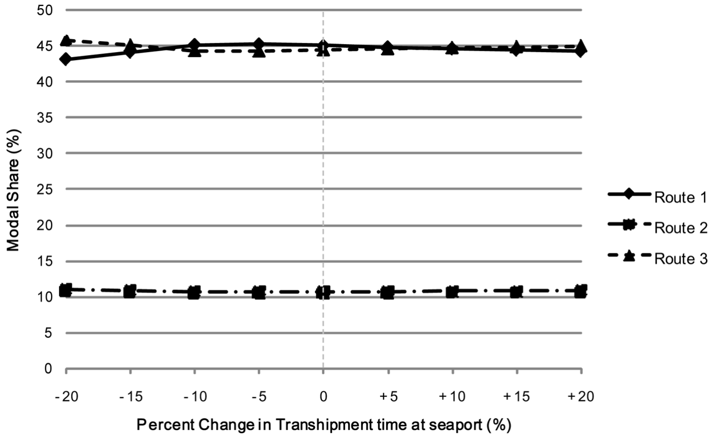


Figure 6, which depicts the modal share in case the transhipment time at seaport is changed, shows that intermodal-waterway transport (route 3) slightly overtakes trailer-only transport (route 1) at the point of 12% reduction and 9% increase in transhipment time at seaport. However, this sensitivity in terms of modal share is not very high. Therefore, the above-mentioned three sensitivity analyses conclude that the results are relatively stable and are hence very likely to be reliable.

Figure 6 Change in each modal share by change in transhipment time at seaport



4 Conclusion

This study focuses on

- the development of a multi-objective optimisation model to determine the optimised modal share through three different modes to minimise the total energy consumption, the total transport time and the total shipment charge
- the measurement of energy saving achieved by using intermodal transport.

These values were calculated within the model. In formulating the model, the LF and EH were added as adjustment factors to reflect the effect of freight loading on energy consumption. Various input parameters in the optimisation model were determined with the aid of a questionnaire survey and a literature-based survey for domestic freight transport in Thailand. The model was applied to the freight transport network between Bangkok and Hat Yai in Thailand. Compared with the actual modal share, a 25% reduction in energy consumption was observed for the base case of the Pareto-optimal solution (45% for trailer-only, 11% for intermodal-rail and 44% for intermodal-waterway transport). It is also revealed that the transport time has a trade-off relationship with energy consumption, and thus, the transport time should be increased to reduce energy consumption. These results are consistent with the finding of previous studies (e.g., Shinke et al., 2007) that a greater modal share of intermodal-rail and intermodal-waterway contributes more energy savings than using trailer-only.

This study shows eight Pareto-optimal solutions, which would be helpful for policy-makers to determine how much modal share of trailer transport should be shifted to intermodal-rail and intermodal-waterway transport to achieve higher energy savings. For example, if the objective of policy in terms of energy savings is to consume less than 10^8 BTU, a policy-maker should aim to achieve a modal share corresponding to alternative 6, 7, or 8 in Table 3. Additionally, the total transport time and the shipment charge can be observed simultaneously. Such a model can help logistics companies and government organisations/agencies to take effective policy decisions to promote intermodal transport for sustainable environment.

As a future work, it is essential to understand the type of commodities that are appropriate for each transport mode. Commodities of higher Value of Time (VOT) might be transported by trailer, which gives better transport times, particularly in Thailand. Then, time constraints might be considered. In this study, detailed information about the type of commodities transported by each mode was unavailable. Such information is highly necessary for further discussion. In terms of capacity, if route 3 (intermodal-waterway) cannot handle all the cargo volume between Bangkok and Hat Yai, a 100% modal share of route 3 cannot be accomplished. Thus, the capacity constraint should also be considered in the model.

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Notes

[1] Exclusive line for freight transport connecting Laem Chabang and ICD has been operating since 1996 by State Railway of Thailand (SRT). Cargo volume transported in this section by rail is more than by trailer in 1997 and 1998, however, cargo volume of trailer caught up with of that by rail in 1999. After that, cargo volume by trailer is continuously increased and finally, cargo volume in 2008 became rail: 25% and trailer 75%, respectively. One of the reasons not to grow cargo volume by rail is due to single-truck problem. SRT is currently considering realising double-truck train in this section (The data were collected in the interview survey to SRT in January 2009).

[2] WWW-NIMBUS can display up to 15 alternative solutions from basic solution to minimum energy consumption.

[3] Proportionally distributed after excluding air transport: trailer: 94.98%, inland waterway: 4.7% and rail: 0.3%.