บทความวิจัย

การเพิ่มประสิทธิภาพการลดต้นทุนและพลังงานเพื่อการส่งออกผลไม้ไทยโดยแบบจำลองหลากหลายวัตถุประสงค์

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DOI: 10.14416/j.kmutnb.2018.12.12
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บทคัดย่อ

ระบบโลจิสติกส์ด้านการขนส่งที่มีประสิทธิภาพมีความสำคัญอย่างมากต่อการส่งออกผลไม้ของไทย เนื่องจากกระบวนการส่งออกผลไม้นั้น เป็นกระบวนการที่ต้องใช้เวลา ค่าใช้จ่าย และการใช้พลังงานในการขนส่งอย่างมาก โดยเฉพาะอย่างยิ่งในฤดูกาลส่งออกที่อุปสงค์ในการใช้บริการรถหัวลาก และตู้คอนเทนเนอร์ของผู้ประกอบการจะเพิ่มขึ้นอย่างมาก เนื่องจากผู้ประกอบการขนส่งส่วนใหญ่นั้นใช้การขนส่งทางถนนเป็นหลัก ดังนั้นผลกระทบที่เกิดขึ้นในช่วงฤดูกาลส่งออกคือ ต้นทุนในการขนส่งทางถนนจะเพิ่มสูงขึ้นอย่างมาก เนื่องจากจำนวนรถหัวลาก และตู้คอนเทนเนอร์ไม่เพียงพอในการให้บริการ ซึ่งก่อให้เกิดการแข่งขันในการแย่งจำนวนรถหัวลาก และตู้คอนเทนเนอร์ขึ้น นอกจากนี้ปัจจัยที่สำคัญอย่างหนึ่งคือ การขนส่งทางถนนก่อให้เกิดมลภาวะทางสิ่งแวดล้อมเป็นอย่างมาก บทความวิจัยนี้นำเสนอวิธีการเพิ่มประสิทธิภาพในการส่งออกผลไม้ไทย โดยการลดต้นทุน และพลังงานเพื่อการอนุรักษ์สิ่งแวดล้อม ภายใต้ขอบเขตของเวลาในการขนส่งผลไม้ที่จำกัด โดยการประยุกต์ใช้แบบจำลองหลากหลายวัตถุประสงค์ที่พัฒนาขึ้นเพื่อทดสอบกับกรณีศึกษาการส่งออกมังคุด โดยตั้งสมมติฐานว่า ผู้ประกอบการมีแหล่งผลิตสินค้าอยู่ 5 จังหวัด และต้องการจะส่งออกมังคุดไปยังต่างประเทศจำนวน 5 ประเทศ ซึ่งจากผลการศึกษาพบว่า ชุดเส้นทางใหม่ที่เสนอขึ้น โดยการหาจุดสมดุลระหว่างต้นทุน และพลังงานในการขนส่ง จะสามารถลดต้นทุนการขนส่งได้ 8.82 เปอร์เซ็นต์ นอกจากนี้การวิเคราะห์ความอ่อนไหวโดยการให้น้ำหนักในมิติของต้นทุน และพลังงานที่แตกต่างกันในหลายกรณีศึกษา ได้ถูกดำเนินการในบทความวิจัยนี้ด้วย

คำสำคัญ: การขนส่งหลายรูปแบบ, โลจิสติกส์ผลไม้, การประหยัดพลังงาน, การอนุรักษ์สิ่งแวดล้อม, แบบจำลองหลากหลายวัตถุประสงค์, การลดต้นทุนและพลังงาน, การวิเคราะห์ความอ่อนไหว

การอ้างอิงบทความ: ศักรธร บุญทวียุวัฒน์, "การเพิ่มประสิทธิภาพการลดต้นทุนและพลังงานเพื่อการส่งออกผลไม้ไทยโดยแบบจำลองหลากหลายวัตถุประสงค์," *วารสารวิชาการพระจอมเกล้าพระนครเหนือ*, ปีที่ 29, ฉบับที่ 2, หน้า 219–236, เม.ย.–มิ.ย. 2562.

Research Article

Optimizing Cost and Energy Effects for Thai Fruit Export by Multi-Objective Optimization Model

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DOI: 10.14416/j.kmutnb.2018.12.12
Received 30 March 2017; Revised 10 October 2018; Accepted 23 November 2018; Published online: 13 December 2018
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Abstract

An efficient transport logistics system is much important for Thailand’s fruit exports because the export process consumes the time, cost and energy immensely. The fruit season comes with the increasing demand for container and trailer services as road transport is often the most flexible and common mode, resulting in substantial increase of transportation costs due to the shortage of export containers and trailers. Besides, road transportation significantly contribute to air pollution and the environmental impacts. This paper presents a methodology to improve efficiency to promote export of Thai fruits through minimizing costs and energy consumption for environmental considerations. A developed Multi-Objective Linear Programming (MOLP) model was applied for a case study investigation involving Thai mangosteen exports. Assuming an operator or exporter has five production sites domestically and fresh products must be exported overseas to five destinations. The results demonstrated the new routes set can reduce transportation costs by 8.82%. Considering different costs of transporting and its energy efficiency, the sensitivity analyses were also carried out in this study.

Keywords: Multimodal Transport, Fruit Logistics, Energy Savings, Environment Conservation, Multi-objective Optimization Model, Cost And Energy Minimizations, Sensitivity Analysis

Please cite this article as: S. Boontaveeyuwat, “Optimizing cost and energy effects for thai fruit export by multi-objective optimization model,” *The Journal of KMUTNB*, vol. 29, no. 2, pp. 219–236, Apr.–Jun. 2019.

1. Introduction

An efficient transport logistics system is important for Thailand's exports because of the need to move commodities from producers to the local collectors and exporters and then to the customers in overseas. Nonetheless, problems have always emerged when the export season arrives, as there are many demands on trailers and container services. Subsequently, the transport cost is much higher than under normal conditions. At present, the exporters or transport operators do not use or believe in other modes of transport in terms of cost and time aspects when compared with road transport. In Thailand, the modal share of domestic freight movement in 2013 based on tonnage was 87.5% by road, 0.65% by waterway, 0.95% by rail and 10% by air. It can been seen that waterway transport accounts for only 0.65% despite this mode of transport having a minimal cost of transport of around US$0.022/ton-km when compared with road (US$0.071/ton-km), rail (US$ 0.032/ton-km) and air transport (US$0.33/ton-km) [1].

The gasoline price has been falling due to the appearance of new energy alternatives; subsequently, the modal share of road transport is rising, resulting in a variety of serious problems such as traffic congestion, noise, vibration and emissions of various gases which can add to greenhouse effects such as increased emission of carbon dioxide (CO_2) and nitrogen oxide (NO_x), etc. In freight movement, road haulage is the most energy-consuming mode of transport compared to rail and water transport in terms of energy efficiency per ton-km. The motivation of this paper is to accommodate an multimodal transport mode, the waterway-road transport mode other than the road transport which is the highest cost and the most energy-consuming mode of transport but the fastest mode of transport to minimize the freight transport cost and energy use under the time constraint.

The objective of this paper was to develop a multi-objective optimization model as the basis for a decision tool suitable for the analysis of any combination of transport modes for the optimal routes of any freight transport. The model results demonstrated the best combination of transport routes between road and waterway modes for fruit export. Mangosteen is selected as a case study in this paper since it is one of the highest value fruits exported from Thailand. The routes from five domestic sources and destinations overseas were selected as the case study. All possible routes from exporters to the final destinations of mangosteen were generated and a new route set for mangosteen exports of Thailand was proposed using a multimodal transport strategy to minimize the costs and energy consumption under time constraint.

2. Literature Reviews and Methods

2.1 *Process of fruit export in thailand*

This section presents the background of the fruit export process from origin to destination. The top five mostly exported fruits of Thailand are Longan, Durian, Mangosteen, Young Coconut and Mango. The mangosteen is selected as a case study in this paper since this fruit was the third mostly exported of Thailand in 2016 [2] and the availability of origin/destination data between Thailand and overseas. The real export process of mangosteen is shown in Figure 1. Firstly, the agriculturists bring

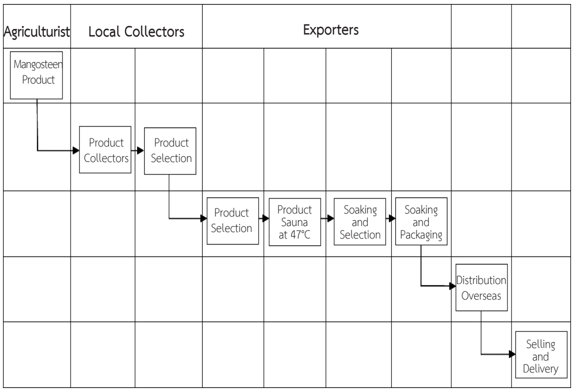

Figure 1: Supply chain diagram from origin to destination of the mangosteen export process in Thailand.

mangosteen products from their gardens to sell at the purchasing point of local collectors from where the local collectors select and sort out the products for domestic selling or exporting depending on the product quality.

The products which pass the criteria for exporting are offered to the exporters. When the products reach the export factories, the mangosteen are selected and sorted by the exporter again. The selected mangosteens are fed into a sauna for 5 hours to eradicate germs and insects and then the mangosteens are removed and allowed to stabilize at normal temperature for 2 hours before soaking in order to select the mangosteens for the final stage. The selected mangosteens are kept in a storage room at room temperature (25–30°C) for 20 hours to adapt the mangosteens to constant conditions. The next process involves sorting the product by size and weighing the products following the customers’ orders through tagging with stickers, wrapping with foam net and placing the product into boxes for keeping in cold storage at 22–25°C. In the next stage, the transport operators repack the boxes containing the mangosteens into 40 foot refrigerated containers at the exporting port before shipping to the final destination overseas.

2.2 *The optimization model*

In this paper, the multi-objective optimization problem was formed as a minimization problem with two variables—cost and energy consumption—under the time constraint of mangosteen preservation and the given volume between origin/destination in order to determine the pareto optimal route set. The various optimization models involved with the stated solutions are reviewed before the presented model is demonstrated in this section.

Rana and Vickson [3] applied the model for routing multiple ships, which was significantly complicated. They presented a mixed integer non-linear programming model to maximize total profit and use the Lagrangean Relaxation and decomposition methods to resolve the complicated algorithms and following Benders’ partitioning method with a specialized algorithm. The results demonstrated the optimal port sequences, cargo allocation and the number of trips for each ship make in a planning horizon. They also recommended the further research to extend and modify the model to be more complicated by adding the alternative route for a ship and some stochastic parameters involving the shipping environment. Cho and Perakis [4] presented the model to help the manager of shipping companies to make a better decision in liner fleet routing problems. The preliminary data of this research is a cargo demands for the planning horizon. They attempted to decide the optimal routes served by different ship types. James and Neil [5] studied the routes and modes of international transport between Canada and Mexico by all possible routes with analysis and calculations in terms of the cost and time of each route. The objective function was to minimize the transport cost under the time constraint. Hwang [6] developed an effective distribution model for determining the optimal patterns of food supply and inventory allocation for a famine relief area.

The complex formulation involved a vehicle routing problem incorporating inventory allocation and optimal distribution based on minimizing the amount of pain and starvation instead of travel distance or time. In addition to the literature focusing solely on the routing, various papers have addressed additional aspects of upstream offshore oil and gas logistics such as fleet composition and robustness [7], [8] Bendall and Stent [9] developed their own fleet planning model to optimize the fleet deployment plan and determined the optimal number of ships and scheduling in high speed containerships for the hub and spoke operation. Singapore is selected as a hub port with 6 spoke ports and 8 voyages to be tested in the case study.

Leung *et al*. [10] developed an optimization model to solve a logistics problem in a Hong Kong-based manufacturing company. The characteristics of similar cross-border logistics problems and alternatives for transporting products were discussed and solved by the robustness and effectiveness of the developed model.

Fagerholt [11] attempted to develop optimal weekly routes along the Norwegian coast for a given fleet of heterogeneous ships. Each ship had the differences of property: a given cost structure, service speed and capacity regarding the number of containers that can be loaded onboard the ship. The customers were defined as the production ports, which were serviced at least once a week. The problem of deciding optimal weekly liner routes was simulated to the multi-trip time constrained VRP. Tzeng *et al*. [12] presented a mathematical model for planning and scheduling coal on time based on minimizing coal costs under demand and supply constraints. The two decision variables in that paper were coal cost and amounts. Li and Pang [13] presented an integrated mathematical model to help shipping companies to operate container vessels as well as self-owned terminals coordinating the routing, berthing time and berth assignment of the vessels.

Some optimization studies were related to the routing problem with vessel selective pickups and deliveries (VRPSPD) problems used to distribute commodities between sources and destinations found in [14]–[17].

All the above optimization models were mostly developed for cost-saving benefits under the time constraint; nonetheless, the developed optimization models involving energy consumption that inspired this paper were Green and Fan [18], Hanaoka *et al*. [19] and Schipper *et al*. [20] as they focused on the evaluation of energy efficiency for the movement of cargoes.

The mathematic model applied to solve problems in this paper aiming to minimize cost and energy consumption and the demand at each destination point under a time constraint is presented below:

$$Min\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{r=1}^{R}\sum_{n=1}^{N}X_{ijr}^{n}C_{ijr}^{n} \tag{1}$$

$$Min\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{r=1}^{R}\sum_{n=1}^{N}X_{ijr}^{n}E_{ijr}^{n} \tag{2}$$

Constraints

$$X_{ijr}^{n}\begin{cases}\geq 0 : T_{ijr}^{n} \leq T_F & \forall i,j,r,n \\ = 0 : T_{ijr}^{n} \geq T_F & \forall i,j,r,n\end{cases} \tag{3}$$

$$\sum_{j=1}^{J}\sum_{r=1}^{R}\sum_{n=1}^{N}X_{ijr}^{n} \leq O_i \quad \forall i \tag{4}$$

$$\sum_{i=1}^{I}\sum_{r=1}^{R}\sum_{n=1}^{N}X_{ijr}^{n} \geq D_j \quad \forall i \tag{5}$$

$$X_{ijr}^{n} \leq N_{ijr} \qquad \forall i,j,r,n \tag{6}$$

$$X_{ijr}^{n} \geq 0 \qquad \forall i,j,r,n \tag{7}$$

where;

Decision Variables

X_{ijr}^{n}: Number of mangosteens carried from the origin point i to the destination point overseas j via route r by the group of trailers and vessels n (Forty-Equivalent Unit – FEU*);

Parameters

N: Number of trailers and vessels in the fleet used for inland transport and one vessel for international transport operating until all mangosteens carried to final destination (trailers or vessels);

T_{ijr}^{n}: Time used for transporting mangosteens from the origin point i to the destination point overseas j via route r by the group of trailers and vessels n (days);

C_{ijr}^{n}: Costs used for mangosteens carried from the origin point i to the destination point overseas j via route r by the group of trailers and vessels n (US$);

E_{ijr}^{n}: Energy used for mangosteens carried from the origin point i to the destination point overseas j via route r by the group of trailers and vessels n (million BTU) ;

T_F: Total time limitation for preserving mangosteens from the origin point i to the destination point overseas j (days) ;

* 1 FEU = 2 TEU (Twenty – Equivalent Unit)

Notations

i: Origin point of transport route;

I: Number of origin points;

j: Destination point of transport route;

J: Number of destination points;

r: Transport route for mangosteen export;

R: Total number of transport routes r for mangosteen export;

n: Trailers and vessels used for inland transport and one vessel for international transport;

O_i: Origin point i which is the production source of mangosteens;

D_j: Destination point j overseas of mangosteens.

The first objective of this optimization model was to minimize cost [Equation (1)] by the different routes and number of cargoes allocated through each route for transport of mangosteens from origin i to destination j. The second objective was to minimize energy consumption [Equation (2)] by the different routes and number of cargoes allocated through each route for transport of mangosteens from origin i to destination j. Energy consumption for transportation by different routes and modes was considered here but ignored the energy utilization at ports for the handling and relocating of containers.

Equations (3)–(7) are constraints of the model. Equation (3) is the scope of total time limitation used for transporting mangosteens from i to j on route r by fleet n and should not exceed the total time constraints of 14 days which represents the time that mangosteens can be preserved in good condition for customers. Equation (4) sets the number of mangosteens transported on routes r from each origin point i to different destinations j which must not be greater than the total amount of mangosteens issued at each origin point i. Equation (5) constrains mangosteens carried from various origin points i to be not less than the total number of mangosteens required at each destination point j. Equation (6) constrains the number of mangosteens transported on each route r so that it does not exceed the fleet capacity. Equation (7) constrains the number of mangosteens selected on each route to be positive.

2.3 *Data entry*

The production and destination sources of mangosteen were selected for the case study in order to determine the optimal routes for mangosteen exports. The criterion of area selection was the top production of mangosteens in Thailand. The top five production sources of mangosteen in 2011 were derived from the Office of Agricultural Economics and are shown below:

1. Krung District, Chanthaburi (CTB) = 77,679 tons
2. Kao Saming District, Trad (T) = 20,896 tons
3. Krang District, Rayong (RY) = 12,547 tons
4. Shwang District, Nakhon Si Thammarat (NST) = 8,922 tons
5. Ranage District Narathiwat (NRT) = 8,380 tons

The figures in parentheses above are the amounts of mangosteen produced in Thailand in 2011. It can be seen that the production sources of mangosteens are mostly in eastern Thailand, with the proportion in the three eastern provinces (Chanthaburi, Trad and Rayong) making up almost 80% of all mangosteen production in Thailand. The destination sources of mangosteens overseas were also selected using the criterion of the amount of mangosteens exported to the top five overseas destinations in 2011. The figures in the parentheses below indicate the amounts of mangosteens exported to the specific ports:

1. Shanghai port, China (CN) = 52,133.50 tons
2. Hong Kong port, Hong Kong (HK) = 25,964.51 tons
3. Danang port, Vietnam (VN) = 21,647.82 tons
4. Busan port, South Korea (SK) = 154.48 tons
5. Yokohama port, Japan (JP) = 140.53 tons

The selection of destinations overseas mainly used the criteria of shipment by vessel for exports, ignoring cross-border road and air transport. In the next stage, all feasible routes to export mangosteens were determined. The information provided by transport operators or exporters indicated the following ports were used for exporting mangosteen and various fruits: Laem Chabang port (LCB), Chonburi province which handled the Post-Panamax containership (4,000–10,000 twenty-foot equivalent units -TEU). The production locations and destination sources in this study are shown in Figure 2.

2.3.1 *All feasible routes for mangosteen exports*

The Leam Chabang (LCB) port was used as the base case in the case study with all feasible routes generated in order to determine the optimal route for mangosteen exports as shown in Table 1. The current route in the base case used the LCB

Figure 2: Location of production and destination sources in this study.

port as the exporting port from the five origin and destination areas, using 4,000 TEU containerships to transport the mangosteens.

All feasible routes showed the various alternative transhipment and exporting ports such as Bangkok (BKK) , Prapadang (PPD), Map Ta Phut (MTP) and Surat Thani (SRT) ports. The port capacity handling the ship size is different in each port as demonstrated by the figures in parentheses in Table 1. The model of transport network was shown in Figure 3 on which the amounts of input cargoes and output cargoes have to be equal depended on the cargoes demands at the destination points.

Finally, the total number of feasible routes constructed from Table 1 was generated for the 300 routes divided by the direct route type without a transhipment port for 100 routes and routes with a transhipment port for 200 routes. Examples of routes generated from Table 1 when RY and HK are used as the case of origin and destination points as shown below:

Base Case : RY – LCB – HK
Route Proposal : RY – BKK – HK ;
RY – PPD – HK ;
RY – MTP – HK ;
RY – BKK – LCB – HK;
RY – BKK – MTP – HK;
RY – PPD – LCB – HK;
RY – PPD – MTP – HK.

2.3.2 *Distance data for fruit exports*

The distance data between the five production and destination sources in each route were determined for every route generated. Examples of route distance data in the base case (production sources (PS) – LCB port – destination port) and other cases are demonstrated in Table 2.

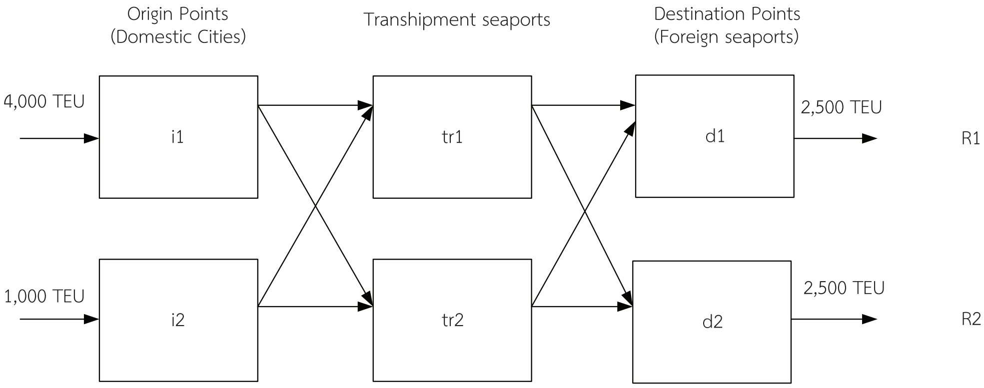

Figure 3: Transportation Networks.

Table 1: All feasible ports and port capacity in route generation for mangosteen exports

Origin	Transhipment Port	Exporting Port	Destination
Rayong (RY)	BKK (1,200 TEU)	LCB* (4,000 TEU)	Hong Kong (HK)
Chanthaburi (CTB)	PPD (1,200 TEU)	BKK (1,200 TEU)	Vietnam (VN)
Trad (T)	SRT (182 TEU)	PPD (1,200 TEU)	South Korea (SK)
Narathiwat (NRT)		MTP (4,000 TEU)	China (CN)
Nakhon Si- Thammarat (NST)			Japan (JP)

* The export port in the base case

Table 2: Examples of route generation and distance data between production and destination sources

Production	Distance (KM)	Transhipment Port	Distance (KM)	Exporting Port	Distance (KM)	Destination Port
RY	-	None	115	LCB	2,616.88	HK
CTB			202		1,889.04	VN
T			238		4,613.33	SK
NRT			1,256		4,068.84	CN
NST			836		5,396.73	JP
RY	-	None	179	BKK	2,702.07	HK
CTB			268		1,968.68	VN
T			301		4,692.97	SK
NRT			1148		4,157.74	CN
NST			725		5,476.36	JP
RY	-	None	190	PPD	2,676.14	HK
CTB			271		1,942.75	VN
T			307		4,667.04	SK
NRT			1,145		4,131.81	CN
NST			730		5,450.44	JP
RY	179	BKK	107.42	LCB	2,616.88	HK
CTB	268		107.42		1,889.04	VN
T	301		107.42		4,613.33	SK
NRT	1148		107.42		4,068.84	CN
NST	725		107.42		5,396.73	JP

2.3.3 *Data for cost, time and energy calculations*

The transport mode in this paper involved land and sea transport; therefore all costs, energy and time involved with these two modes were considered. A 22-wheeled trailer which can load a 40-foot container (Forty-foot Equivalent Unit - FEU), holding approximately 25 tons was selected for this paper. Costs calculated for the trailer were composed of the gasoline cost both forward and backward, port tariffs and shipping costs which were based on the vessel's daily operating costs per container, with the calculation shown in Figure 4 which depicts the economies of scale achieved by charter shipping for geared and gearless vessel up to 4,000 TEU [21].

Baird [22] also supported this conceptual approach asserting that the value of a ship's time can be measured by the prevailing daily time or charter rate or, for owned ships, the daily ship capital and operating costs. Furthermore, time charter rates (dependent on the voyage distance and ship size) being more visible and more standard, provide for much greater clarity and scrutiny as appropriate and representative measures of ship provision costs.

The speed of each vessel depends on the ship size and was derived from interviews with shipping operators as shown in Table 3. The speed of the vessel was also involved in quantifying the energy consumption derived from [23].

Table 3: Ship Sizes Speed

Ship Size (TEU)	Speed (knots)
≥ 5,100	24
3,000–5,099	23
2,000–2,999	21
1,000–1,999	18
500–900	16
< 500	13

Source: Derived from interviews with domestic and international shipping operators

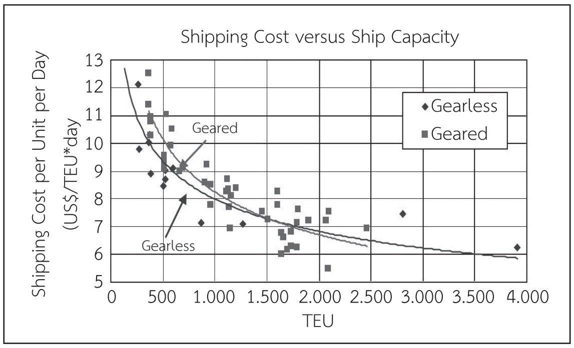

Figure 4: Economies of scale of shipping cost Source: Aversa *et al*. [21].

The energy consumption for land transportation in the domestic movement from production sources to transhipment or exporting ports were calculated in the forward and backward directions. Energy efficiency was used to measure energy consumed per tonne-km of freight carried by estimating the energy used and dividing it by the tonnage carried times the route kilometers covered.

In this study, the energy efficiency of a particular mode and route was determined by Equation (8).

$$\begin{aligned} \mu_k = {} & 139{,}000 / (3.7854\ e_k\ V_k) \ \ \text{(Diesel case)} \\ & 153{,}200 / (3.7854\ e_k\ V_k) \ \ \text{(Fuel oil case)} \end{aligned} \tag{8}$$

where;

μ_k: energy efficiency of mode k (BTU/TEU-km);
e_k: fuel consumption of mode k (km/litre);
V_k: average shipment weight by mode k (TEU);
1 gallon = 3.7854 liter, 1 gallon of diesel = 139,000 BTU; 1 gallon of fuel oil = 153,200 BTU.

The load factor of the average shipment weight was 0.8; therefore, a 4,000 TEU ship can load cargoes up to 3,200 TEU in this study. Basically, the transport mode which uses the lower energy, always has the lower cost too but the negative aspect is the time consumed at the higher level.

In this study, the time constraint for mangosteen preservation was imposed at 14 days for serving 3,390 FEU or around 212 FEU/day. The average speed of a trailer was set at 70 km/hour and the number of trailers which can operate simultaneously was set at 50 trailers/time. The speed of a crane working on cargo handling was 15 FEU/hour/crane assuming two cranes can be used simultaneously, therefore the lifting rate of cranes was set at 30 FEU/hour. The Equation (9) for the time calculation was determined by the following equation:

$$T_r N_{rt} + W_{Tr} N_{FEU} + T_{SS} + W_{Ex} N_{FEU} + T_{SM} + W_D N_{FEU} \quad (9)$$

where;

T_r: road transport time from origin point to transhipment or export port (day);

N_{rt}: number of round trip from origin point to transhipment or export port (trip);

W_{Ex}: working rate of crane at export port (FEU/hour);

W_{Tr}: working rate of crane at transhipment port (FEU/hour);

N_{FEU}: number of 40-foot container (FEU);

T_{SS}: shipping time from transhipment port to export port (day);

T_{SM}: shipping time from export port to port destination (day);

W_D: working rate of crane at destination port (FEU/hour).

The overall conceptual flowchart of the research methodology used in this paper is shown in Figure 5.

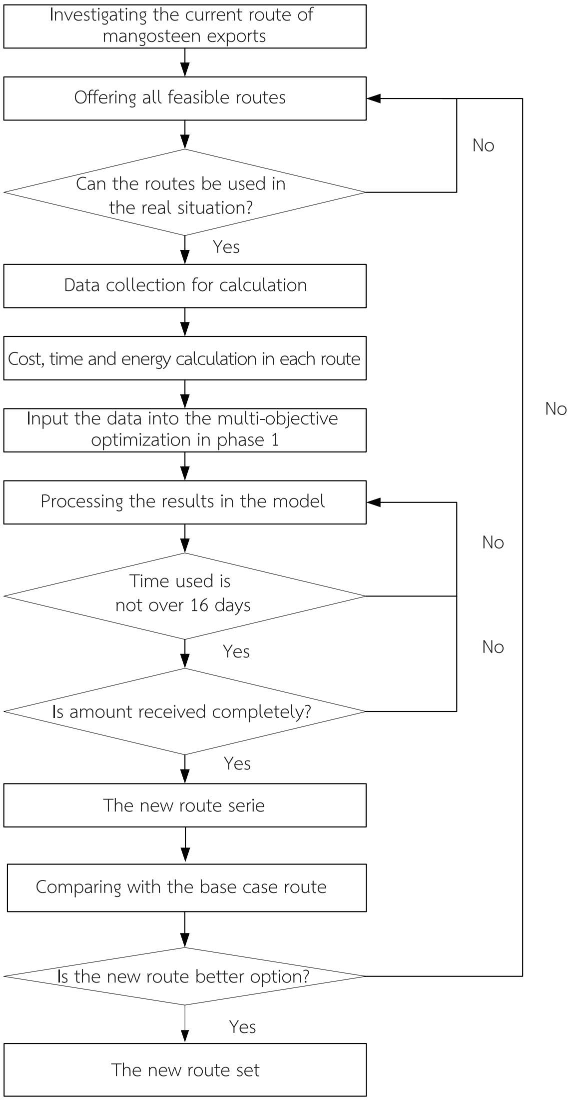

Figure 5: Conceptual flowchart of methodology in this study.

3. Results and Discussion

The model was operated using a spreadsheet for parameter calculations and then run using by Branch and Bound algorithm. The results of cost and energy consumption in the base case are calculated and they were derived from the model containing the pareto optimal new routes for cost and energy minimization with different numbers of mangosteens assigned to each route.

Finally, the optimal new routes with the combined number of mangosteens assigned to each route through cost and energy minimization using multi-objective optimization were analyzed. The weights (w_c = weight of cost; w_e = weight of energy) assigned to cost and energy functions were equally set as 1 in the base case.

The results of cost, time and energy consumption in the base case are demonstrated in Table 4. The research implication is to minimize cost and energy consumption in the equal priority on optimal solutions. The results derived from the model containing the optimal new routes for cost and energy minimization with different numbers of mangosteens assigned to each route are demonstrated in Tables 5 and 6, respectively. Table 7 shows the results of the optimal new routes with the combined number of mangosteens assigned to each route through cost and energy minimization using multi-objective optimization on the base case.

Table 4 shows the results in terms of cost, energy and time with the number of mangosteens in containers for each route. It can be seen that the total cost and energy are US$ 987,318.70, 4,920.92 million BTU or around 1.45 million BTU/FEU with total number of containers dispatched to destinations being 3,390 FEU. The time used on each route met the requirement of the time constraint to not exceed 14 days.

Table 5 shows the results for the optimal routes derived from the model for cost minimization only (Case I). It can be seen that the total cost of this new route group was US$ 814,298.28 which reduced the cost from the base case by 17.52%. Nonetheless, the energy consumption was more than the base case.

Table 6 demonstrates the results of the optimal new routes for energy consumption minimization only (Case II). It can be seen that the total energy consumption was merely 4,467.28 million BTU which reduced the energy consumption from the base case by 9.21% and the cost was also reduced by 2.71%.

Table 7 demonstrates the results of the optimal new routes derived from the multi-objective optimization model involving cost and energy consumption minimization under the time constraint in which the weighting parameter of cost and energy was 1 (Case III). It can be seen that the total cost and energy of this new route were US$ 900,184.51 and 4,934.57 million BTU respectively which reduced the cost from the base case by 8.83% but the energy was slightly more than the base case.

It can be seen that there is a route (NRT – SRT – MTP – HK) which has the transshipment through the SRT port. It was found that this port’s position can offer efficient alternative routes for operators in southern Thailand in terms of cost and energy consumption minimization. It is observed the time used for each route in Table 4–7 was limited to not exceed 14 days as required and the total number of mangosteens dispatched to all destinations used 3,390 FEU.

The sensitivity analyses were conducted in this paper by giving the weights of cost and energy in different four cases as shown : 1) w_c = 1, w_e = 5; 2) w_c= 1, w_e = 10; 3) w_c= 5, w_e = 1 and 4) w_c = 10, w_e = 1; The results of sensitivity analysis of four cases demonstrated in Table 8 – 11 as shown continuously in Case IV - VII respectively.

Table 4: Results of cost, time and energy consumption in determining current route for mangosteen export (Base Case)

Route	Cost (US$)	Energy (Million BTU)	Time (Day)	Number of Containers (FEU)
RY - LCB - HK	12,717.32	86.51	3.42	86
RY - LCB - VN	9,936.00	61.19	2.56	72
RY - LCB - SK	205.62	3.13	5.91	1
RY - LCB - CN	26,920.57	157.36	5.08	173
RY - LCB - JP	221.77	3.61	6.89	1
CTB - LCB - HK	111,729.94	656.70	6.00	532
CTB - LCB - VN	88,263.00	475.57	4.71	441
CTB - LCB - SK	1,071.05	13.42	6.03	4
CTB - LCB - CN	232,342.53	1,214.34	10.15	1067
CTB - LCB - JP	851.75	11.50	7.00	3
T - LCB - HK	33,709.82	190.04	3.88	143
T - LCB - VN	26,877.00	139.58	2.97	119
T - LCB - SK	293.48	3.45	6.06	1
T - LCB - CN	69,875.13	353.77	5.86	287
T - LCB - JP	309.63	3.93	7.03	1
NRT - LCB - HK	53,921.05	224.16	4.61	56
NRT - LCB - VN	45,744.00	184.65	3.79	48
NRT - LCB - SK	1,020.62	6.12	7.27	1
NRT - LCB - CN	112,590.78	453.16	6.12	116
NRT - LCB - JP	1,036.77	6.60	8.25	1
NST - LCB - HK	40,435.43	176.88	4.14	61
NST - LCB - VN	33,303.00	139.93	3.30	51
NST - LCB - SK	720.62	5.02	6.77	1
NST - LCB - CN	82,485.06	344.82	5.66	123
NST - LCB - JP	736.77	5.50	7.75	1
Total	**987,318.70**	**4,920.92**	**10.15***	**3,390**

* Maximum Time used for transport

Table 5: Results of cost, time and energy consumptions in the new route group for mangosteen exports for cost minimization (Case I)

Route	Cost (US$)	Energy (Million BTU)	Time (day)	Number of Containers (FEU)
RY - MTP - CN	46,136.19	258.98	5.86	333
CTB - MTP - HK	17,342.11	98.29	3.41	90
CTB - MTP - VN	93,041.16	475.64	4.97	509
CTB – MTP - SK	2,011.65	25.85	5.99	8
CTB – MTP - CN	287,691.08	1,442.29	12.12	1,433
CTB – MTP - JP	1,862.59	25.66	6.87	7
T – MTP - HK	120,340.81	653.88	6.03	551
NRT - SRT - MTP - VN	148,220.97	2,854.38	4.58	222
NST - SRT - MTP - HK	97,651.72	3,685.41	4.94	237
Total	**814,298.28**	**9,520.37**	**12.12***	**3,390**

Table 6: Results of cost, time and energy consumption for the new route group for mangosteen export for energy consumption minimization (Case II)

Route	Cost (US$)	Energy (Million BTU)	Time (day)	Number of Containers (FEU)
RY - MTP - VN	40,152.40	234.99	3.89	333
CTB – MTP - HK	169,181.89	958.91	7.82	878
CTB - MTP - VN	72,751.24	371.92	4.35	398
CTB – MTP – CN	154,787.04	776.00	8.41	771
T – MTP – CN	124,788.10	606.67	7.22	551
NRT – PPD - JP	6,747.51	44.88	8.21	7
NRT - PPD – SK	7,582.19	47.38	7.24	8
NRT – PPD – LCB - CN	211,763.48	785.52	6.62	207
NST – PPD – LCB - CN	172,200.27	641.02	6.29	237
Total	**959,954.13**	**4,467.28**	**8.41***	**3,390**

Table 7: Results of cost, time and energy consumption for the new route group for mangosteen export for cost and energy consumption minimization (Case III, W_{cost} = 1, W_{energy} = 1)

Route	Cost (US$)	Energy (Million BTU)	Time (Day)	Number of Containers (FEU)
RY - MTP – HK	43,448.44	287.50	4.67	333
CTB - MTP – HK	97,693.87	553.72	5.74	507
CTB - MTP – CN	309,172.55	1,549.98	12.72	1,540
T-MTP-VN	67,764.56	334.43	3.99	325
T-MTP-CN	51,183.50	248.84	5.40	226
NRT – PPD – VN	157,424.57	711.31	4.78	177
NRT – PPD – JP	6,747.51	44.88	8.21	7
NRT-SRT-MTP-HK	25,747.28	494.58	4.54	38
NST– PPD-SK	5,210.76	38.66	6.75	8
NST – PPD - VN	135,791.46	670.67	4.58	229
Total	**900,184.51**	**4,934.57**	**12.72***	**3,390**

Table 8: Results of cost, time and energy consumption for the new route group for mangosteen export for cost and energy consumption minimization (Case IV, W_{cost} = 1, W_{Energy} = 5)

Route	Cost (US$)	Energy (Million BTU)	Time (Day)	Number of Containers (FEU)
RY - MTP – CN	46,136.19	258.98	5.86	333
CTB- MTP- HK	138,736.86	786.35	6.94	720
CTB – MTP – CN	266,410.37	1,335.60	11.53	1,327
T-MTP-HK	34,507.89	187.50	3.83	158
T-MTP-VN	81,943.00	404.40	4.37	393
NRT – PPD – VN	197,447.77	892.16	5.03	222
NST – LCB – CN	71,084.68	297.16	5.57	106
NST – PPD – SK	5,210.76	38.66	6.75	8
NST– PPD – JP	4,672.51	37.25	7.72	7
NST – PPD - VN	68,785.19	339.73	3.95	116
Total	**914,935.22**	**4,577.78**	**11.53***	**3,390**

Table 9: Results of cost, time and energy consumption for the new route group for mangosteen export for cost and energy consumption minimization (Case IV, W_{cost} = 1, W_{energy} = 10)

Route	Cost (US$)	Energy (Million BTU)	Time (Day)	Number of Containers (FEU)
RY - MTP – VN	10,610.84	62.10	2.51	88
RY - MTP – CN	33,944.04	190.54	5.36	245
CTB - MTP – HK	169,181.89	958.91	7.82	878
CTB-MTP-CN	234,690.07	1,176.58	10.64	1169
CTB-MTP-VN	100,718.43	514.89	5.21	551
NRT – LCB – CN	111,620.17	449.25	6.12	115
NRT – PPD – VN	81,825.20	369.72	4.31	92
NRT – PPD – SK	7,582.19	47.38	7.24	8
NRT– PPD – JP	6,747.51	44.88	8.21	7
NST – LCB - CN	158,934.62	664.40	6.30	237
Total	**915,854.97**	**4,478.65**	**10.64***	**3,390**

Table 10: Results of cost, time and energy consumption for the new route group for mangosteen export for cost and energy consumption minimization (Case IV, W_{cost} = 5, W_{energy} = 1)

Route	Cost (US$)	Energy (Million BTU)	Time (Day)	Number of Containers (FEU)
RY - MTP – HK	43,448.44	287.50	4.67	333
CTB - MTP – HK	73,222.23	415.02	5.03	380
CTB - MTP – CN	334,669.25	1,677.81	13.43	1,667
T-MTP-VN	94,244.87	465.12	4.70	452
T-MTP-CN	22,421.09	109.00	4.69	99
NRT-PPD-VN	37,354.98	168.79	4.03	42
NRT-PPD-SK	7,582.19	47.38	7.24	8
NRT-PPD-JP	6,747.51	44.88	8.21	7
NRT-SRT-MTP-HK	111,797.41	2,147.52	5.96	165
NST – PPD-VN	140,535.26	694.09	4.62	237
Total	**872,023.24**	**6,057.11**	**10.63**	**3,390**

Table 11: Results of cost, time and energy consumption for the new route group for mangosteen export for cost and energy consumption minimization (Case IV, W_{cost} = 10, W_{energy} = 1)

Route	Cost (US$)	Energy (Million BTU)	Time (Day)	Number of Containers (FEU)
RY - MTP – VN	40,152.40	234.99	3.89	333
CTB - MTP – HK	126,404.69	716.45	6.58	656
CTB - MTP – CN	279,259.10	1,400.02	11.88	1,391
T-MTP-VN	36,697.12	181.11	3.15	176
T – MTP – CN	84,928.38	412.89	6.24	375
NRT – SRT – MTP – HK	150,418.33	2,889.39	5.36	222
NST – PPD – VN	121,560.04	600.38	4.45	205
NST – PPD – SK	5,210.76	38.66	6.75	8
NST– PPD – JP	4,672.51	37.25	7.76	7
NST – SRT - MTP - VN	6,836.29	261.67	2.93	17
Total	**856,139.62**	**6,772.81**	**10.63**	**3,390**

They can be observed that when increasing the relative weight on the energy in Case IV and V, the optimal results can save energy from the base case by 6.97% and 8.99% respectively. Moreover, they also save costs from the base case by 7.33% and 7.23% in Case IV (Table 8) and V (Table 9) respectively. It can be observed that when the energy is more saved, the cost is less saved which is the trade-off objectives of MOLP.

On the concurrent way, when increasing the relative weight on the cost in Case VI (Table 10) and VII (Table 11), the optimal results can save cost from the base case by 11.68% and 13.29% respectively. Nonetheless, they do not save the energy consumption on both cases.

In summary, it can be observed that when the model focused on cost optimization only in Case I, the optimal route set can provide the minimum total cost compared with other cases (Base Case, Case II - VII). Nonetheless, it provides the worst result in the total energy consumption. Whilst the energy consumption was optimized only in Case II, it can provide the most advantage aspects in energy consumptions compared with other cases (Base Case, Case I, Case III – VII) but the worst result appeared in total cost but still better than the base case. Finally, Case III – VII provides the multi-objective solution to optimize both cost and energy consumptions by putting the equal priority on these two aspects in Case III and different relative weight in Case IV-VII for sensitivity analysis purpose. The results demonstrated that the new route group can save both cost and energy from the base case in Case IV and V only in which both cases were assigned the relatively increased weight of energy at 5 and 10 times respectively.

4. Conclusion

The multi-objective optimization model offered in this paper can assist operators or exporters in their decision making for the selection of optimal routes for fruit exportation aiming to minimize cost and energy consumption under time constraint. The results derived from the model can reduce both cost and energy when increasing the relative weight assigned to energy for 5 and 10 times in Case IV and V respectively. The outcomes derived from the results will be invaluable because the new route group will offer the reduced number of vehicles on the road dramatically which results in a substantial decrease in noise, vibration, air pollution and the number of accidents on the road.

The highlight of the results is the new route group when assigning the increased weight on energy that could reduce the cost and energy simultaneously from the base case around 7% ($w_c = 1$, $w_e = 5$) and 9% ($w_c = 1$, $w_e = 10$) for energy savings and around 7% for cost savings. The results derived from the model can be immensely beneficial to the private and public sectors in Thailand in terms of economic and environmental gains. The model offers a straightforward decision tool for all transport operators or exporters in any cargoes putted on the container not only the mangosteen or other fruits aspiring to reduce costs and energy usage under time constraint for container exporting. Furthermore, the involved government organizations should use the benefits derived from the results of this paper to execute the effective policy oriented decisions to promote multimodal transport more than the present case for sustainable environment and cost saving.

References

[1] Office of Transport and Traffic Policy and Planning. (2014, July). Thailand's Transport Infrastructure Development Strategy 2015–2022. Office of Transport and Traffic Policy and Planning. Bangkok, Thailand [Online] Available : http://www.mot.go.th/mot_strategy/index.php

[2] Office of Agricultural Regulation. (2016, October). Thailand's Fruit Export 2016. Department of Agriculture. Bangkok, Thailand [Online]. Available: http://www.doa.go.th/ard/FileUpload/export/5.4.2/FRUIT59.pdf

[3] K. Rana and R. G. Vickson, "Routing containerships using lagrangean relaxation and decomposition," *Transportation Science*, vol. 22, pp. 201–214, 1991.

[4] S. C. Cho and A. N. Perakis, "Optimal liner fleet routing strategies," *Maritime Policy and Management*, vol. 23, pp. 249–259, 1996.

[5] H. James and S. Neil. "Intermodal routing of Canada-Mexico shipments under NAFTA," *Transport Research Part E: Logistics and Transportation Review*, vol. 34, no. 4, pp. 289–303, 1998.

[6] H. S. Hwang. "A food distribution model for famine relief," *Computer & Industrial Engineering*, vol. 37, no. 1–2, pp. 335–338, 1999.

[7] E. Halvorsen-Weare , K. Fagerholt, L. M. Nonas, and B. E. Asbjornslett, "Optimal fleet composition and periodic routing of offshore supply vessels," *European Journal of Operation Research*, vol. 223, no. 2, pp. 508–517, 2012.

[8] E. K. Norlund, I. Gribkovskaia, and G. Laporte, "Supply vessel planning under cost, environment and robustness considerations," *Omega*, vol. 57, pp. 271–281, 2015.

[9] H. B. Bendall and A. F. Stent. "A scheduling model for a high speed container service: A hub and spoke short-sea application," *International Journal of Maritime Economics*, vol. 3, no. 3, pp. 262–277, 2001.

[10] S. C. H. Leung, Y. Wu, and K. K. Lai. "An optimization model for a cross-border logistics problem: A case in Hong Kong," *Computer & Industrial Engineering*, vol. 43, pp. 393–405, 2002.

[11] K. Fagerholt, "A computer-based decision support system for vessel fleet scheduling-experience and future research," *Decision Support System*, vol. 37, no. 4, pp. 35–47, 2004.

[12] G. H. Tzeng, M. J. Hwang, and S. C. Ting, "Taipower's coal logistics system: Allocation Planning and bulk fleet deployment," *International Journal of Life Cycle Assessment*, vol. 25, pp. 24–46, 1995.

[13] C. L. Li and K. W. Pang, "An integrated model for ship routing and berth allocation," *International Journal of Shipping and Transport Logistics*, vol. 3, no. 3, pp. 245–260, 2011.

[14] M. Battarra, J-F. Cordeau, and M. Iori, "Pickup-and-delivery problems for goods transportation," in *Vehicle Routing: Problems, Methods and Applications*, Philadelphia: MOS-SIAM Series on Optimization, 2014, pp. 161–181.

[15] G. Laporte, S. Ropke, and T. Vidal, "Heuristics for the vehicle routing problem," in *Vehicle routing: problems, methods and applications*, Philadelphia: MOS-SIAM Series on Optimization, 2014, pp. 87–110.

[16] J. E. Korsvik , K. Fagerholt, and G. Laporte, “A large neighbourhood search heuristic for ship routing and scheduling with split loads,” *Computer Operation Research*, vol. 38, no. 2, pp. 474–483, 2011.

[17] A. Hemmati, L. M. Hvattum, K. Fagerholt, and I. Norstad, “Bechmark suite for industrial and tramp ship routing and scheduling problems,” *INFOR: Infornation System Operation Research*, vol. 52, no. 1, pp. 28–38, 2014.

[18] D. L. Greene and Y. Fan, “Transportation energy intensity trends: 1972–1992,” *Transport Research Record*, vol. 1475, pp. 10–19, 1994.

[19] S. Hanaoka, T. Husnain, T. Kawasaki, and P. Kunadhamraks, “Measurement of energy-saving effect by intermodal freight transport in Thailand,” *World Review of Intermodal Transportation Research*, vol. 3, no. 4, pp. 320–337, 2011.

[20] L. Schipper, L. Scholl, and L. Price, “Energy use and carbon emissions from freight in 10 industrialized countries: An analysis of trends from 1973 to 1992,” *Transport Research Part D Transport and Environment*, vol. 2, no. 1, pp. 57–76, 1997.

[21] R. Aversa, R. C. Botter, H. E. Haralambides, and H. T. V. Yoshisaki, “A mixed integer programming model on the location of a hub port in the East Coast of South America,” *Maritime Economic & Logistics*, vol. 7, no. 1, pp. 1–18, 2005.

[22] A. J. Baird, “Optimising the container transhipment hub location in Northern Europe,” *Journal of Transport Geography*, vol. 14, no. 3, pp. 195–214, 2006.

[23] J. P. Rodrigue, *The Geography of Transport System*, 3rd ed. Routledge, 2013.