บทความวิจัย

ผลกระทบจากราคาสปอตและราคาฟิวเจอร์ในการขนส่งน้ำมันเครื่องบิน: กรณีศึกษาเส้นทางการขนส่งเอเชียตะวันออกเฉียงใต้

เสาวนิตย์ เลขวัต* และ ณกร อินทร์พยุง
สาขาวิชาการจัดการโลจิสติกส์และโซ่อุปทาน คณะโลจิสติกส์ มหาวิทยาลัยบูรพา

* ผู้นิพนธ์ประสานงาน โทรศัพท์ 09 2456 4247 อีเมล: saowanit.le@go.buu.ac.th DOI: 10.14416/j.kmutnb.2023.07.001
รับเมื่อ 8 เมษายน 2564 แก้ไขเมื่อ 10 กันยายน 2564 ตอบรับเมื่อ 14 กันยายน 2564 เผยแพร่ออนไลน์ 3 กรกฎาคม 2566

บทคัดย่อ

วัตถุประสงค์ของงานวิจัยนี้ คือ การเสนอแบบจำลองทางคณิตศาสตร์สำหรับการสำรวจผลกระทบจากราคาสปอตและราคาฟิวเจอร์ในการขนส่งน้ำมันเครื่องบินในโซ่อุปทาน โดยใช้การพยากรณ์แบบดั้งเดิม คือ การพยากรณ์แบบอนุกรมเวลาสำหรับการพยากรณ์ราคาสปอต หลังจากนั้นนำราคาดังกล่าวเป็นตัวแปรนำเข้าของแบบจำลองทางคณิตศาสตร์ที่นำเสนอสำหรับการหาเส้นทางขนส่งน้ำมัน โดยใช้กรณีศึกษาของเส้นทางการขนส่งน้ำมันจากสถานีถังน้ำมันในประเทศสิงคโปร์มายังสถานีถังน้ำมันในประเทศไทย และจากสถานีถังน้ำมันในไปเทศไทยส่งไปยังสนามบินต่างๆ ท้ายที่สุดได้มีการทดลองเพื่อศึกษาผลกระทบของหลายๆ ปัจจัยในห่วงโซ่อุปทาน และผลการศึกษาพบว่า ราคาสปอตและราคาฟิวเจอร์มีผลกระทบต่อเส้นทางการขนส่งเมื่อพิจารณา 1 ระดับ ในห่วงโซ่อุปทาน

คำสำคัญ: ราคาสปอตและราคาฟิวเจอร์ การจัดสรร น้ำมันเครื่องบิน เอเชียตะวันออกเฉียงใต้

การอ้างอิงบทความ: เสาวนิตย์ เลขวัต และ ณกร อินทร์พยุง, “ผลกระทบจากราคาสปอตและราคาฟิวเจอร์ในการขนส่งน้ำมันเครื่องบิน: กรณีศึกษาเส้นทางการขนส่งเอเชียตะวันออกเฉียงใต้,” *วารสารวิชาการพระจอมเกล้าพระนครเหนือ*, ปีที่ 33, ฉบับที่ 3, หน้า 1–16, เลขที่บทความ 233-154913, ก.ค.–ก.ย. 2566.

Research Article

The Impact of Spot and Futures Price in Allocating Jet Fuel: A Case Study of Southeast Asia Routes

Saowanit Lekhavat* and Nakorn Indra-payoong
Logistics and Supply Chain Management, Faculty of Logistics, Burapha University, Chonburi, Thailand

* Corresponding Author, Tel. 09 2456 4247, E–mail: saowanit.le@go.buu.ac.th DOI: 10.14416/j.kmutnb.2023.07.001
Received 8 April 2021; Revised 10 September 2021; Accepted 14 September 2021; Published online: 3 July 2023

Abstract

The aim of this research is to propose mathematical models for investigating the effect of spot and future price in allocating jet fuel in the supply chain. Traditional forecasting method which is time series is applied to predict the spot price of jet fuel. Then, it is used as an input for the proposed allocation model. A case study of jet fuel allocating from tank terminals in Singapore to tank terminals in Thailand and from tank terminals in Thailand to the airports was investigated. Finally, experiments were conducted to investigate the impact of various factors in the supply chain. The result shows that spot and future prices have an impact on the allocation routes when considering only a single echelon in the supply chain.

Keywords: Spot and Future Price, Allocation, Jet Fuel, Southeast Asia

Please cite this article as: S. Lekhavat and N. Indra-payoong, "The impact of spot and futures price in allocating jet fuel: A case study of southeast asia routes," *The Journal of KMUTNB*, vol. 33, no. 3, pp. 1–16, ID. 233-154913, Jul.–Sep. 2023.

1. Introduction

Jet fuel cost is one of the major cost sources for airlines. It is accounted for around a quarter to a half of total costs for airline industry firm in 2014 [1]. The future ticket price is estimated by the jet fuel cost in the airline industry firms. If the jet fuel cost is high, the ticket price tends to increase no matter there will be high demands for air travel or not. Therefore, in order for the airline industry to reduce this price ticket, one of the significant ways is to try to minimize this cost.

Over the past decades, the prices of jet fuel have been fluctuated significantly with changes in market prices. In order to reduce this risk and obtain a competitive advantage, practically, airlines handle this problem by applying hedging strategy to the jet fuel prices [2]. For example, one of the airline companies indicates that hedging strategy is used to purchase jet fuel at a specific price and at a set date in the futures contract between the airline firm and its supplier [3].

To hedge against the uncertainty of fuel prices, airline industry can buy a futures contract of fuel price at a specific price, quantity, and length of time. The airline company, therefore, does not need to worry about the fluctuation of jet fuel price. If the jet fuel price increases above the price that is agreed in the futures contract, the hedge is successful. This is because the airline company can save money because the lower price has been paid. On the other hand, if the price goes down, the airline company can select another option which is spot price to save the fuel cost. In order to increase the revenue to the airline, the whole supply chain of jet fuel is considered.

Supply chain network design problem is one of the optimization models that studies how to allocate products from the origins to the destinations. The research begins with single type of product, single echelon, simple linear and deterministic model to a more complex network considering multiple types of product multiple echelons and nonlinear stochastic model [4]. It has been applied to various types of application such as humanitarian relief logistics, wastewater treatment, bio-energy system, etc [5]–[7].

To the best of our knowledge, there is no research applying supply chain network design model on a case study of transporting jet fuel in Southeast Asia routes. This study, therefore, focuses on determining the allocation routes of jet fuel from tank terminals in Singapore to tank terminals in Thailand and tank terminals in Thailand to the airports in order to minimize total costs. Apart from jet fuel price in spot or futures contract, the other important cost which should be saved is transportation costs. It is also main cost due to the distance in the supply chain.

The main contribution of this study is divided into three issues. The first one is to forecast the spot and futures price by using time series method. Then, these spot and futures prices are used in the proposed model to investigate the effect of these prices in the supply chain. The third one is the managerial rules for transporting jet fuel from tank terminals in Singapore to tank terminals in Thailand and to the airports in Thailand in various configurations which are the number of echelons, transportation type of vehicles, and demand.

2. Materials and Methods

2.1 Time Series Method

Time series is one of the forecasting methods that observations are collected over time [8]. For example, spot and futures price of jet fuel are collected at the end of every day. The unit of time may be every day, every week, every month, or every year or others. It is normally used to forecast the business's future value such as sale, cost or profit, etc. The general form of the model is presented in Equation (1). It shows the past behavior of the observations in order to predict the future.

$$\hat{Y}_{t+1} = f\left(Y_t, Y_{t-1}, Y_{t-2}, \ldots\right) \quad (1)$$

Where $\hat{Y}_{t+1}$ stands for the predicted value of the variable at time period $t+1$. Y_t is an actual value of observation at time t. Y_{t-1} is an actual value of observation at time $t-1$, etc.

The basic methods include simple moving average, weighted moving average and exponential smoothing. Simple moving average is the easiest technique of time series. It is simply the average of k previous observations as demonstrated in Equation (2).

$$\hat{Y}_{t+1} = \frac{\left(Y_t + Y_{t-1} + \ldots + Y_{t-k+1}\right)}{k} \quad (2)$$

A drawback of simple moving average is that the weights that are assigned to each data are assigned equally. Hence, weighted moving average is suggested to handle the disadvantage of simple moving average by assigning different weights to data. The forecasting function is shown in Equation (3).

$$\hat{Y}_{t+1} = w_1 Y_t + w_2 Y_{t-1} + \ldots. + w_k Y_{t-k+1} \quad (3)$$

Where $0 \le w_i \le 1$ and $\sum_{i=1}^{k} w_i = 1$. w_i is a weight of data i

Exponential smoothing is another averaging technique but assigns the weight to only the most recent data. The predicted value of time period $t+1$ is equal to the predicted value of time period t plus a difference of the actual value with the predicted value of time period t that is multiplied by the weight. This equation is shown in Equation (4).

$$\hat{Y}_{t+1} = \hat{Y}_t + \alpha\left(Y_t - \hat{Y}_{t-1}\right) \quad (4)$$

Where $0 \le \alpha \le 1$ α is a weight

Mean Square Error (MSE) can provide a clear difference of error and spot price is money. If it is estimated incorrectly, it may lead to lose the profit. Therefore, in order to measure accuracy, this study executes MSE as presented in Equation (5).

$$MSE = \sum_{i=1}^{n} \frac{\left(Y_i - \hat{Y}_i\right)^2}{n} \quad (5)$$

2.2 Mathematical Model

Players in jet fuel supply chain consist of airports, tank terminals in Thailand and tank terminals in Singapore. The airport plays a role in buying jet fuel from tank terminal in Thailand in order to consume by itself or in other words, in order to fill up the gas tank. Tank terminal in Thailand is an actor who gains benefit from margin between selling and purchasing price. The terminal in Thailand receives jet fuel from tank terminal in Singapore. Tank terminal in Singapore is a player that receives the jet fuel from the Middle East. This route of

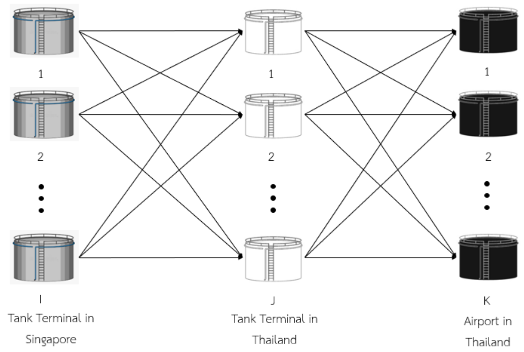

Figure 1 Supply chain network design of jet fuel

supply chain has a similar model with supply chain network design as demonstrated in Figure 1 [9], [10]. We, therefore, adapt the mathematical model from them as follows.

Indices:

i = Tank terminal in Singapore i ; $i = 1, 2, 3, \ldots, I$

j = Tank terminal in Thailand j ; $j = 1, 2, 3, \ldots, J$

k = Airport k ; $k = 1, 2, 3, \ldots, K$

Parameters:

Q_k = Demand of airport k (barrel)

ρj = Capacity of tank terminal in Thailand (barrel)

η_i = Capacity of tank terminal in Singapore i (barrel)

S_{ij} = Spot price at tank terminal in Singapore i to tank terminal in Thailand j (dollars per barrel)

F_{ij} = Futures price at tank terminal in Singapore i to tank terminal in Thailand j (dollars per barrel)

S_{jk} = Spot price at tank terminal in Thailand j to airport k (dollars per barrel)

F_{jk} = Futures price at tank terminal in Thailand j to airport k (dollars per barrel)

k_1, k_2 = Bunker fuel consumption coefficients

v = Economical speed of a vessel (knots or nautical miles per hour)

$g_{ij}(v)$ = Bunker fuel consumption rate during the sea from tank terminal in Singapore i to tank terminal in Thailand j (tons per nautical mile)

IFO = Bunker fuel price (dollars/ton)

d_{jk} = Distance from tank terminal in Thailand j to airport k (km)

d_{ij} = Distance from tank terminal in Singapore i to tank terminal in Thailand j (nautical miles)

RT = Truck consumption rate (liters/km)

CT = Transportation cost of diesel (dollars/liter)

Decision Variables:

Y_{ij} = Quantity of jet fuel that is transported from tank terminal in Singapore i to tank terminal in Thailand j

Z_{jk} = Quantity of product distribute from tank terminal in Thailand j to airport k

$$M = \begin{cases} 1; \textit{ spot price is selected} \\ 0; \textit{ future price is selected} \end{cases}$$

Model 1: Single Echelon of benchmark model (without spot and futures price)

$$Min \sum_j \sum_k d_{jk} Z_{jk} CT/RT \tag{6}$$

$$\sum_j Z_{jk} \geq Q_k \qquad \forall k \tag{7}$$

$$\sum_k Z_{jk} \leq \rho_j \qquad \forall j \tag{8}$$

According to model 1, in order to minimize transportation cost from tank terminals in Thailand to airports as shown in Equation (6). The decision-maker has to decide how much jet fuel is sent from tank terminals in Thailand to airports. Therefore, constraint set (7) ensures that jet fuel which is transported from tank terminals in Thailand satisfies the demands of all airports. Constraint set (8) makes sure that those tank terminals in Thailand have enough capacity to send jet fuel to the airports.

Model 2: Single Echelon of proposed model (including spot and futures price)

$$Min \sum_j \sum_k \begin{pmatrix} \left[M \times S_{jk} + (1-M) \times F_{jk}\right] \\ + d_{jk} CT / RT \end{pmatrix} \times Z_{jk} \quad (9)$$

According to model 2, in order to minimize total costs which are consisted of transportation cost from tank terminals in Thailand to airports and spot price and futures price as shown in equation (9). The transportation routes are the same as shown in equation (7) and (8).

Model 3: 2 Echelons of truck-truck model (without spot and futures price)

$$Min \begin{matrix} \left(\sum_j \sum_k d_{jk} Z_{jk} CT / RT \right) \\ + \left(\sum_i \sum_j d_{ij} Y_{ij} CT / RT \right) \end{matrix} \quad (10)$$

$$\sum_j Y_{ij} \le \eta_i \qquad \forall i \quad (11)$$

$$\sum_i Y_{ij} \ge \sum_k Z_{jk} \qquad \forall j \quad (12)$$

According to model 3, the objective function is to minimize transportation costs from tank terminals in Singapore to tank terminal in Thailand and from tank terminals in Thailand to airport as shown in Equation (10). Jet fuel which is transported from tank terminals in Thailand satisfies the demands of all airports and tank terminals in Thailand have enough capacity to send jet fuel to the airports are the same as in model 1 as presented in Equation (7) and (8). Constraint set (11) makes sure that those tank terminals in Singapore have enough capacity to send jet fuel to tank terminals in Thailand. Constraint set (12) ensures that the total volumes of jet fuel sent from tank terminals in Singapore to tank terminals in Thailand fulfill those from tank terminals in Thailand to airports.

Model 4: 2 Echelons of proposed truck-truck model (including spot and futures price)

$$Min \begin{matrix} \sum_j \sum_k \begin{pmatrix} \left[M \times S_{jk} + (1-M) \times F_{jk}\right] \\ + d_{jk} CT / RT \end{pmatrix} Z_{jk} \\ + \sum_i \sum_j \begin{pmatrix} \left[M \times S_{ij} + (1-M) \times F_{ij}\right] \\ + d_{ij} CT / RT \end{pmatrix} Y_{ij} \end{matrix} \quad (13)$$

According to model 4, the objective function which is equation (13) is replaced with equation (10) in model 3 in order to minimize total costs which are consisted of transportation costs from tank terminals in Thailand to airports as well as tank terminals in Singapore to tank terminals in Thailand and spot price and futures price. The remaining constraints are the same as model 3.

Model 5: 2 Echelons of vessel-truck model (without spot and futures price)

$$Min \begin{matrix} \left(\sum_j \sum_k d_{jk} Z_{jk} CT / RT \right) \\ + \left(\sum_i \sum_j IFOY_{ij} \, g_{ij}(v) \right) \end{matrix} \quad (14)$$

According to model 5, in order to minimize transportation costs from tank terminals in Singapore to tank terminals in Thailand and from tank terminals in Thailand to airport as shown in Equation (14). In this case, it is a case when using vessel to transport jet fuel from tank terminals in Singapore to tank terminals in Thailand. A vessel which is used to carry the jet fuel is a handy size one. Fuel consumption function of this vessel is, therefore, adopted to compute transportation cost in the first echelon [11] and in the second echelon, the trucks are used to transport jet fuel. The decision-maker has to decide how much jet fuel is sent from tank terminals in Singapore to tank terminals in Thailand and from tank terminals in Thailand to airports are presented in constraints in model 3.

Model 6: 2 Echelons of proposed vessel-truck model (including spot and futures price)

$$Min \quad \sum_{j}\sum_{k}\left(\begin{array}{l}\left[M\times S_{jk}+(1-M)\times F_{jk}\right]\\+d_{jk}CT/RT\end{array}\right)Z_{jk} + \sum_{i}\sum_{j}\left(\begin{array}{l}\left[M\times S_{ij}+(1-M)\times F_{ij}\right]\\+IFOg_{ij}(v)\end{array}\right)Y_{ij} \qquad (15)$$

According to model 6, the model includes spot price and futures price in addition to transportation cost as shown in Equation (15). It is also 2 echelons of vessel-truck model. Therefore, the remaining transportation constraints are the same as in model 5.

3. Results

3.1 Forecast Spot and Future Price

Spot price is the market price at time period t which is the period that is focused on. In this study, traditional forecasting analytics are applied to forecast the spot price. This is demonstrated as follows. This is noted that spot price is collected from public website [12].

Table 1 Forecasting spot price for Phra Khanong (BKK) and Don Muang

Month	Spot price (dollar per barrel)	Simple moving average 2 periods	Simple moving average 7 periods	Weighted moving average 2 periods	Weighted moving average 7 periods	Exponential smoothing
1/3/2019	59.99					59.99
1/4/2019	62.38					59.99
1/5/2019	62.20					62.38
1/6/2019	57.31	61.52		62.20		62.20
1/7/2019	60.36	60.63		57.31		57.31
1/8/2019	56.79	59.96		60.36		60.36
1/9/2019	59.12	58.15		56.79		56.79
1/10/2019	58.71	58.76	59.74	59.12	59.12	59.12
1/11/2019	57.55	58.21	59.55	58.71	58.71	58.71
1/12/2019	59.60	58.46	58.86	57.55	57.55	57.55
1/1/2020	56.06	58.62	58.49	59.60	59.60	59.60
1/2/2020	47.74	57.74	58.31	56.06	56.06	56.06
1/3/2020	30.07	54.47	56.51	47.74	47.74	47.74
1/4/2020	47.74				30.07	
1/5/2020	30.07				47.74	
1/6/2020	47.74				30.07	
1/7/2020	30.07				47.74	
1/8/2020	47.74				30.07	
1/9/2020	30.07				47.74	
1/10/2020	47.74				30.07	
1/11/2020	30.07				47.74	
1/12/2020	47.74				30.07	
1/1/2021	30.07				47.74	
1/2/2021	47.74				30.07	
	MSE	21.649	24.665	17.509	17.509	17.509

From Table 1, five methods are compared which are simple moving average 2 periods, simple moving average 7 periods, weighted moving average 2 periods, weighted moving average 7 periods and exponential smoothing to forecast spot price for Phra Khanong (BKK) and Don Muang. The number of periods which is presented in this example is one of the example cases. For the remaining cases, these are shown in [13]. For weighted moving average 2 and 7 periods, the parameters are obtained from optimization method which is presented in [8] that minimizes MSE by using open solver. The best method to forecast spot price is weighted moving average 2 or 7 periods or exponential smoothing because it gives the minimum MSE. This is noted that n is equal to 6.

Futures price is the price that is fixed at period t from the previous period ($t-1$, $t-2$ and so on) because it is the price which has been negotiated between tank terminals in Singapore to tank terminals in Thailand and to the airports in Thailand in order to hedge against uncertainty in the future. The data which is collected from the public website [14] from 2 April 2020 to 8 April 2020 is presented in Table 2. The average value of such collected data is used in the proposed model.

Table 2 Futures price

Month	Future price (dollars per barrel)					
	4/2/2020	4/3/2020	4/5/2020	4/6/2020	4/8/2020	Average
2/2021	44.976	44.976	45.832	45.832	45.832	45.4896

3.2 Allocation Route of Jet Fuel from Singapore to Thailand

One of the input data in this study is bunker fuel consumption rate during the sea $\left(\left(\frac{d_{ij}}{v_{ij}}\right)k_1v^3+k_2\right)\Big/24$ tons per nautical mile = $0.004595v^3+16.42$ for vessel size 1001 to 2000 TEU fuel consumption function [11] which can be converted to 17,000 tons (a vessel size that transports jet fuel from Singapore to Thailand) [15].

For bunker fuel price (dollars/ton), it is set to $315.00 in Singapore [16]. Truck consumption rate (RT) (kms/liter) = 5 km/liter. Transportation cost of diesel (CT) (dollars/liter) = 20 Bahts/liter * 0.033 dollar = 0.66 dollars/liter. This is noted that the exchange rate is on 16th December 2020. Economical speed of vessel is 12.5 knots. Route from tank terminals in Singapore to tank terminals in Thailand and tank terminals in Thailand to airports, distance between each node, capacity at each tank terminal, demand of jet fuel at the airport, spot and futures price, unit transportation cost are presented in Table 1 to 8.

For bunker fuel price (dollars/ton), it is set to $315.00 in Singapore [16]. Truck consumption rate (kms/liter) = 5 km/liter. Transportation cost of diesel (dollars/liter) = 20 Bahts/liter * 0.033 dollar = 0.66 dollars/liter. This is noted that the exchange rate is on 16th December 2020. Economical speed of vessel is 12.5 knots. Route from tank terminals in Singapore to tank terminals in Thailand and tank terminals in Thailand to airports, distance between each node, capacity at each tank terminal, demand of jet fuel at the airport, spot and futures price, unit transportation cost are presented in Table 1 to 8.

We note that A refers to Pasir Panjang Terminal 5 Canteen (Singapore Petroleum Co. Ltd. (Sebarok)). B refers to Brani Terminal (PetroSeraya Pte. Ltd.). C refers to Jurong (Universal Terminal (S) Pte. Ltd.). D refers to Jurong (Horizon Singapore Terminals Pvt. Ltd.). Moreover, X refers to Phra Khanong (BKK) and Y refers to Ko Si Chang. Also, M refers to Don Muang. N refers to Samui. O refers to Suchothai. P refers to Suwannapoom. Q refers to Trat.

Table 3 Distance from tank terminals in Singapore to tank terminals in Thailand by truck (km)

Distance	X	Y
A	1,862.00	1,950.00
B	1,863.00	1,951.00
C	1,862.00	1,949.00
D	1,861.00	1,948.00

Table 4 Distance from tank terminals in Singapore to tank terminals in Thailand by vessel (nautical miles)

Distance	X	Y
A	865.00	784.00
B	865.00	784.00
C	844.00	797.00
D	844.00	797.00

Table 5 Distance from tank terminals in Thailand to airports (km)

Distance	M	N	O	P	Q
X	31.5	761	437	30.8	309
Y	134	869	561	91	247

Table 6 Unit transportation cost from tank terminals in Singapore to tank terminals in Thailand when using truck, their capacities, spot price and related total costs (transportation cost and spot price)

From/To	X	Y	Capacity
A	245.78	257.40	1,383,759.00
B	245.92	257.53	5,472,138.00
C	245.78	257.27	14,655,267.00
D	245.65	257.14	7,874,847.00
Demand	597,846.51	-	
Spotcost	30.07	33.47	
	32.66	30.07	
	30.07	32.66	
	30.07	30.07	
Total Cost (Dollars)	275.85	290.87	
	278.57	287.60	
	275.85	289.92	
	275.73	287.21	

Table 7 Unit transportation cost from tank terminals in Singapore to tank terminals in Thailand when using vessel, their capacities, spot price and related total costs

From/To	X	Y	Capacity
A	288,308.17	261,310.53	1,383,759.00
B	288,308.17	261,310.53	5,472,138.00
C	281,308.79	265,643.49	14,655,267.00
D	281,308.79	265,643.49	7,874,847.00
Demand	-	896,769.77	
Spotcost	30.07	33.47	
	32.66	30.07	
	30.07	32.66	
	30.07	30.07	
Total Cost (Dollars)	288,338.24	261,344.00	
	288,340.83	261,340.60	
	281,338.86	265,676.14	
	281,338.86	265,673.56	

Table 8 Unit transportation cost from tank terminals in Thailand to airports, their capacities, spot price and related total costs

From/To	M	N	O	P	Q	Capacity
X	4.16	100.45	57.68	4.07	40.79	628,981.00
Y	17.69	114.71	74.05	12.01	32.60	1,866,062.00
Demand	119,506.40	6,289.81	157.25	471,735.81	157.25	597,846.51
Spot Cost	30.07	40.36	33.47	32.66	30.07	
	30.07	40.42	33.47	32.66	40.58	
Total Cost (Dollars)	4.16	100.45	57.68	4.07	40.79	
	17.69	114.71	74.05	12.01	32.60	

Table 6, 7 and 8 show the unit transportation cost from tank terminals in Singapore to tank terminals in Thailand when using truck, when using vessel and unit transportation cost from tank terminals in Thailand to airports, respectively. They also present the capacities of each tank terminal, futures price and spot price, in order to calculate whether spot price or futures price should be selected so that total related costs will be minimized. The spot price from each source to sink is forecasted by time series method which are presented in [10]. Spot price of February 2021 is used as a price in Table 6–8. The average future price of February 2021 from Table 2 is also used as input data. We note that spot price for all transportation routes are selected because it is cheaper than future price.

After data is collected from a real case, the experiment is conducted to investigate the effect of spot and futures price at various scenarios. For example, the effect of spot price and futures price if only single echelon of jet fuel in Thailand is considered. This means that considering the route from tank terminals in Thailand to airports. The second group is to investigate jet fuel in supply chain from tank terminals in Singapore to Thailand, and tank terminals in Thailand to airports by truck route. The third group is to investigate jet fuel in supply chain from tank terminals in Singapore to Thailand, and tank terminals in Thailand to airports by vessel route. We also conduct the experiment to see the impact of demand if the demand increases 150%, 200% and 300%. These scenarios are shown in Table 9.

3.2.1 The effect of spot and futures price on single echelon

According to scenarios 1 and 2, the cases show the allocation cases of single echelon from tank terminals in Thailand to airports. The investigation is conducted on the effect of spot and futures price when the normal demand. It is noted that all cases of spot price is less than futures price. Therefore, total costs are consisted of spot prices and transportation costs. In this comparison, jet fuel from all airports does not exceed the capacity of Phra Khanong (BKK) tank terminal. From Table 8, spot price is greater than unit of transportation. This leads to the change of allocation route from Phra Khanong (BKK) tank terminal to airport at Trat

Table 9 The experiment to investigate the effect of spot price and future price at various scenarios

Input	Level	Transport mode	Demand	Effect of sport and future price
S1	1 Echelon	Truck	Current	Existing mode of transportation
S2				The effect of spot and future price
S3			150%	Existing mode of transportation
S4				The effect of spot and future price
S5			200%	Existing mode of transportation
S6				The effect of spot and future price
S7			300%	Existing mode of transportation
S8				The effect of spot and future price
S9	2 Echelons	Truck-Truck	Current	Existing mode of transportation
S10				The effect of spot and future price
S11			150%	Existing mode of transportation
S12				The effect of spot and future price
S13			200%	Existing mode of transportation
S14				The effect of spot and future price
S15			300%	Existing mode of transportation
S16				The effect of spot and future price
S17		Truck-Vessel	Current	Existing mode of transportation
S18				The effect of spot and future price
S19			150%	Existing mode of transportation
S20				The effect of spot and future price
S21			200%	Existing mode of transportation
S22				The effect of spot and future price
S23			300%	Existing mode of transportation
S24				The effect of spot and future price

to Ko Si Chang tank terminal to airport at Trat as demonstrated in Table 10 and 11 because total unit cost from Ko Si Chang tank terminal to airport at Trat is less than those from Phra Khanong (BKK) tank terminal to airport at Trat.

Table 10 Quantity of jet fuel transport from tank terminal in Thailand to airports

From/To	M	N	O	P	Q	Capacity
X	119,506.40	6,289.81	157.25	471,735.81	-	597,689.27
Y	-	-	-	-	157.25	157.25
Demand	119,506.40	6,289.81	157.25	471,735.81	157.25	597,846.51

Table 11 Quantity of jet fuel transport from tank terminal in Thailand to airports

From/To	M	N	O	P	Q	Capacity
X	119,506.40	6,289.81	157.25	471,735.81	157.25	597,846.51
Y	-	-	-	-	-	-
Demand	119,506.40	6,289.81	157.25	471,735.81	-	597,689.27

3.2.2 The effect of spot and futures price on single echelon when the demand increases

According to scenarios 3 and 8, the cases show the allocation cases of single echelon from tank terminals in Thailand to airports. This comparison is made to investigate the effect of spot and future price when the demand increases 150%, 200% and 300%. In this situation, jet fuel of all airports cannot be satisfied by only one tank terminal in Thailand. The result shows that there are no different between allocation routes. This is because even though unit price of total cost from Phra Khanong (BKK) tank terminal to airport at Trat is less than those from Ko Si Chang tank terminal to airport at Trat, its capacity cannot meet the demands. Therefore, the remaining demand is received from Ko Si Chang tank terminal as presented in Table 12 and 13.

Table 12 Quantity of jet fuel transport from tank terminals in Thailand to airports

From/To	M	N	O	P	Q	Capacity
X	179,259.61	9,434.72	235.87	440,050.81	-	628,981.00
Y	-	-	-	267,552.90	235.87	267,788.77
Demand	179,259.61	9,434.72	235.87	707,603.71	235.87	896,769.77

Table 13 Quantity of jet fuel transport from tank terminals in Thailand to airports

From/To	M	N	O	P	Q	Capacity
X	358,519.21	18,869.43	471.74	251,120.62	-	628,981.00
Y	-	-	-	1,164,086.80	471.74	1,164,558.54
Demand	358,519.21	18,869.43	471.74	1,415,207.42	471.74	1,793,539.53

3.2.3 The effect of spot and futures price on 2 echelons by truck

According to scenarios 9 and 10, the cases show the allocation cases of 2 echelons from tank terminals in Singapore to tank terminals in Thailand, and from tank terminals in Thailand to airports. The transportation of fuel is transported by truck. This study investigates the effect of spot and future price when the normal demand. In this situation, jet fuel of all airports does not exceed the capacity of Phra Khanong (BKK) tank terminal. This tank terminal is also received from the nearest tank terminal in Singapore which is Jurong (Horizon Singapore Terminals Pvt. Ltd.) as shown is Table 14. From Table 2 and 7, these show that the spot price is less than futures price while spot prices is greater than unit of transportation. Hence, unit total prices include spot prices and unit of transportation costs. Even though unit total prices from Ko Si Chang tank terminal to airport at Trat is less than those from Phra Khanong (BKK) tank terminal to airport at Trat, the allocation route in the first echelon from tank terminal in Singapore from only one nearest tank terminal is enough to transport to Phra Khanong (BKK) tank terminal. Therefore, even if spot price or futures price should be able to change the allocation route by common sense, the result can appear the opposite as presented in Table 15.

Table 14 Quantity of jet fuel transport from tank terminals in Singapore to tank terminals in Thailand

From/To	X	Y	Capacity
A	-	-	-
B	-	-	-
C	-	-	-
D	597,846.52	-	597,846.52
Demand	597,846.52	-	597,846.52

Table 15 Quantity of jet fuel transport from tank terminals in Thailand to airports

From/To	M	N	O	P	Q	Capacity
X	119,506.40	6,289.81	157.25	471,735.81	157.25	597,846.51
Y	-	-	-	-		-
Demand	119,506.40	6,289.81	157.25	471,735.81	157.25	597,846.51

3.2.4 The effect of spot and futures price on 2 echelons by truck when the demand increases

According to scenarios 11 and 16, the cases show the allocation cases of 2 echelons from tank terminals in Singapore to tank terminals in Thailand, and from tank terminals in Thailand to airports. The transportation of fuel is transported by truck. We investigate the effect of spot and futures price when the demand increases 150, 200 and 300%. The result demonstrates that jet fuel of all airports cannot be met by only one tank terminal. This can be seen that the nearest tank terminal in Singapore which is Jurong (Horizon Singapore Terminals Pvt. Ltd.) is transported to both Phra Khanong (BKK) and Ko Si Chang tank terminals as shown in Table 16 and 17.

Table 16 Quantity of jet fuel transport from tank terminals in Singapore to tank terminals in Thailand

From/To	X	Y	Capacity
A	-	-	-
B	-	-	-
C	-	-	-
D	628,981.00	267,788.77	896,769.77
Demand	628,981.00	267,788.77	896,769.77

Table 17 Quantity of jet fuel transport from tank terminals in Thailand to airports

From/To	M	N	O	P	Q	Capacity
X	179,259.61	9,434.72	235.87	440,050.81	-	628,981.00
Y	-	-	-	267,552.90	235.87	267,788.77
Demand	179,259.61	9,434.72	235.87	707,603.71	235.87	896,769.77

If the impact of spot and futures price are considered, the route also demonstrates that there is no effect of this parameter as presented in Table 18 and 19. The reason for this may be that the gap between the spot price and unit transportation cost is not large enough to change the result. This applies to all increasing cases of demand.

Table 18 Quantity of jet fuel transport from tank terminals in Singapore to tank terminals in Thailand

From/To	X	Y	Capacity
A	-	-	-
B	-	-	-
C	-	-	-
D	628,981.00	1,164,558.50	1,793,539.50
Demand	628,981.00	1,164,558.50	1,793,539.50

Table 19 Quantity of jet fuel transport from tank terminals in Thailand to airports

From/To	M	N	O	P	Q	Capacity
X	358,519.21	18,869.43	471.74	251,120.62	-	628,981.00
Y	-	-	-	1,164,086.80	471.74	1,164,558.54
Demand	358,519.21	18,869.43	471.74	1,415,207.42	471.74	1,793,539.53

3.2.5 The effect of spot and futures price on 2 echelons by vessel

According to scenario 17 and 18, the cases show the allocation cases of 2 echelons from tank terminals in Singapore to tank terminals in Thailand, and from tank terminals in Thailand to airports. The transportation of fuel is transported by vessel. The result of the investigation for the effect of spot and futures price in this situation is that the demand of jet fuel of all airports can be met by only one tank terminal which is Ko Si Chang tank terminal as presented in Table 21. This tank terminal is also received the jet fuel from only one nearest tank terminal in Singapore which is Brani Terminal (Singapore Petroleum Co. Ltd. (Sebarok)) as seen in Table 20.

Table 20 Quantity of jet fuel transport from tank terminals in Singapore to tank terminals in Thailand

From/To	X	Y	Capacity
A	-	597,846.51	597,846.51
B	-	-	-
C	-	-	-
D	-	-	-
Demand	-	597,846.51	597,846.51

When looking at the impact of spot and futures price, the route also demonstrates that there is no effect of this parameter as shown in Table 22 and 23. The reason for this is that the dominant factor of transportation cost from tank terminals in Singapore to tank terminals in Thailand.

Table 21 Quantity of jet fuel transport from tank terminals in Thailand to airports

From/To	M	N	O	P	Q	Capacity
X	-	-	-	-	-	-
Y	119,506.40	6,289.81	157.25	471,735.81	157.25	597,846.51
Demand	119,506.40	6,289.81	157.25	471,735.81	157.25	597,846.51

Table 22 Quantity of jet fuel transport from tank terminals in Singapore to tank terminals in Thailand

From/To	X	Y	Capacity
A	**-**	**597,846.51**	**597,846.51**
B	-	-	-
C	-	-	-
D	-	-	-
Demand	-	597,846.51	

Table 23 Quantity of jet fuel transport from tank terminals in Thailand to airports

From/To	M	N	O	P	Q	Capacity
X	-	-	-	-	-	-
Y	119,506.40	6,289.81	157.25	471,735.81	157.25	597,846.51
Demand	119,506.40	6,289.81	157.25	471,735.81	157.25	597,846.51

3.2.6 The effect of spot and futures price on 2 echelons by vessel when the demand increases

According to scenario 19 and 22, the cases show the allocation cases of 2 echelons from tank terminal in Singapore to tank terminals in Thailand, and from tank terminals in Thailand to airports. The transportation of fuel is transported by vessel and the demand increases 150% and 200%. The result of the investigation of the effect of spot and futures price in this situation is that the demand of jet fuel of all airports can be met by only one tank terminal which is Ko Si Chang tank terminal as presented in Table 25 and 27. This tank terminal is also received the jet fuel from only one nearest tank terminal in Singapore which is Brani Terminal (Singapore Petroleum Co. Ltd. (Sebarok)) as shown in Table 24 and 26. However, as shown in scenario 23 and 24, the demand increases 300%, we can see that the jet fuel in the nearest tank terminal in Singapore which is Brani Terminal (Singapore Petroleum Co. Ltd. (Sebarok)) and the second nearest tank terminal which is Brani Terminal (PetroSeraya Pte. Ltd.) are transported to Ko Si Chang tank terminal. Even though the route can be changed when the demand increase, impact of spot and futures price, the route also demonstrates that there is no effect of this parameter. The reason for this is that the dominant factor of transportation cost from tank terminals in Singapore to tank terminals in Thailand.

Table 24 Quantity of jet fuel transport from tank terminals in Singapore to tank terminals in Thailand

From/To	X	Y	Capacity
A	-	896,769.77	896,769.77
B	-	-	-
C	-	-	-
D	-	-	-
Demand	-	896,769.77	896,769.77

Table 25 Quantity of jet fuel transport from tank terminals in Thailand to airports

From/To	M	N	O	P	Q	Capacity
X	-	-	-	-	-	-
Y	179,259.61	9,434.72	235.87	707,603.71	235.87	896,769.77
Demand	179,259.61	9,434.72	235.87	707,603.71	235.87	896,769.77

Table 26 Quantity of jet fuel transport from tank terminals in Singapore to tank terminals in Thailand

From/To	X	Y	Capacity
A	-	1,195,693.00	1,195,693.00
B	-	-	-
C	-	-	-
D	-	-	-
Demand	-	1,195,693.00	1,195,693.00

Table 27 Quantity of jet fuel transport from tank terminals in Thailand to airports

From/To	M	N	O	P	Q	Capacity
X	-	-	-	-	-	-
Y	239,012.81	12,579.62	314.49	943,471.62	314.49	1,195,693.03
Demand	239,012.81	12,579.62	314.49	943,471.62	314.49	1,195,693.03

4. Conclusion

This research proposes a mathematical model and managerial rules for allocating jet fuel in supply chain when considering the effect of spot and future price. The transportation route is determined from tank terminals in Singapore to tank terminals in Thailand and to the airports so that the jet fuel is added to the airplane. The study is divided into 2 sections. The first section is to forecast the spot and futures price of jet fuel by traditional forecasting method which is time series. Then, the second section is to propose a mathematical model find the allocation route of jet fuel in the supply chain. Open solver is used to search for the optimal solution to minimize the total costs that consists of transportation cost and the effect of spot and futures price cost. The result shows that spot and future price of jet fuel has an impact on transportation route when considering only single echelon in the supply chain.

However, there are also some gaps to suggest for further study. For example, other forecasting methods such as time series considering seasonal effect or machine learning method may be another option to use for forecasting spot price. Second, stochastic model is suggested to investigate the effect of spot and futures price in transporting jet fuel in the supply chain. Third, different types of vessel and truck should be used to conduct the experiment.

5. Acknowledgement

This research was supported by Faculty of Logistics, Burapha University.

Reference

[1] C. Koopmans and R. Lieshout, "Airline cost changes: To what extent are they passed through to the passenger?," *Journal of Air Transport Management*, vol. 53, pp. 1–11, 2016.

[2] D. A. Carter, D. A. Rogers, and B. J. Simkins, "Hedging and Value in the U.S. Airline Industry," *Journal of Applied Corporate Finance*, vol. 18, no. 4, pp. 21–33, 2006.

[3] P. Morrell and W. Swan, "Airline jet fuel hedging: Theory and practice," *Transport Reviews: A Transnational Transdisciplinary Journal*, vol. 26, no. 6, pp. 713–730, 2006.

[4] C. Sreyneath and S. Lekhavat, "Systematic literature review for location-allocation problem under economic and environmental sustainability," *Kasem Bundit Engineering Journal*, vol. 9, no.3, pp. 253–274, 2019.

[5] P. Praneetpholkrang, V. N. Huynh, and S. Kanjanawattana, "A multi-objective optimization model for shelter location-allocation in response to humanitarian relief logistics," *The Asian Journal of Shipping and Logistics*, vol. 37, no. 2, pp. 149–156, 2021.

[6] S. Chandra, M. Sarkhel, and A. K. Vatsa, "Capacitated facility location–allocation problem for wastewater treatment in an industrial cluster," *Computers and Operations Research*, vol. 132, 2021.

[7] E. C. Chukwuma, "Facility location allocation modelling for bio-energy system in Anambra State of Nigeria: Integration of GIS and location model," *Renewable Energy*, vol. 141, pp. 460–467, 2019.

[8] C. T. Ragsdale, "Spreadsheet Modelling and Decision Analysis," 8th ed. Boston, 2016, pp. 1–845.

[9] Y. Hinojosa, J. Kalcsics, S. Nickel, J. Puerto, and S. Velten, "Dynamic supply chain design with inventory," *Computers and Operations Research*, vol. 35, no. 2. pp. 373–391, 2008.

[10] S. Lekhavat, "Allocation methods for multi-commodity distribution network design problem," in *Proceedings Smart Logistics Conference*, 2018, pp. 104 – 120.

[11] Z. Yao, S. H. Ng, and L. H. Lee, "A study on bunker fuel management for the shipping liner services," *Computer and Operations Research*, vol. 39, no. 5, pp. 1160–1172, 2012.

[12] OpenDataSoft. [Online]. Available: https://data.opendatasoft.com/explore/dataset/spot-prices-for-kerosene-type-jet-fuel-1990-2016%40kapsarc/export/?sort=period&q.timerange.period=period:%5B2019-03-31T17:00:00Z+TO+2020-03-31T16:59:59Z%5D.

[13] S. Lekhavat and N. Indra-payoong, "Decision support system of hedging oil price in oil supply chain," Completed Report, Faculty of Logistics, Burapha University, 2020 (in Thai).
[14] Singapore Jet Kerosene (Platts). (2021, September). Futures [Online]. Available: https://www.cmegroup.com/trading/energy/refined-products/singapore-jet-kerosene-swap-futures.html
[15] Conversion Center. (2021). *Conversion Center* [Online]. Available: https://www.conversioncenter.net/volume-conversion/from-TEU-(4.25-ft-height)-to-freight-ton
[16] BunkerEx. (2021). *Bunker price* [Online]. Available: https://www.bunker-ex.com/bunker-prices/