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Cost analysis of air cargo transport and effects of fluctuations in fuel price

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A B S T R A C T

This study developed a model with cost functions formulated for different stages of cargo transport operation. A case analysis was performed with actual data from four air cargo traffic routes and eight aircraft types to validate the applicability of the model. The results show that the optimal payloads for various aircraft types vary with fuel price fluctuations. Furthermore, this study determined optimal types of freighter aircraft for different routes. Freight rates increase with rises in fuel price due to the corresponding increase in the fuel surcharge, thus bringing in higher total revenue. When the increase in total revenue exceeds the rise in fuel cost, the optimal payload will drop. Not only can the cost functions reveal the impact of fuel price fluctuations on different aspects of air cargo transport, they can also assist airlines in selecting the aircraft type with the best fuel economy for different route distances and cargo volumes.

1. Introduction

With the rapid developments in technology and new electronic products frequently appearing on the market, the past few decades have witnessed substantial growth in international air cargo transport under a closely linked global supply chain. Air cargo traffic increased from about 11 million tonnes in 1980 to about 49 million tonnes in 2011, an average growth of almost 4.9% per year; while seaborne trade only grew about 2.9% annually during the same time period.[1] According to the Boeing World Air Cargo Forecast (Boeing, 2012), global air cargo traffic will expand at an average annual rate of 5.2% for the next two decades.

Previous studies on the cost of air transport and choice of aircraft type have focused mainly on passenger traffic (e.g. Tsoukalas et al., 2008; Givoni and Rietveld, 2010; Takebayashi, 2011). Notable in the cargo area is Kupfer et al. who accounted for airport choice for freighter operations using the method of stated preference (2012a) and identified factors influencing airport choice of freighter operators using a multinomial logit model (2012b).

As with passenger transport, air cargo transport involves both direct and indirect operation costs. Direct operation costs are expenses associated with purchase or lease of aircraft and related equipment, as well as their maintenance fees; while indirect operation costs are expenses related to internal management and ground operations (see Fig. 1). In addition, the operation cost for each flight is made up of fixed and variable costs. Fixed costs, which do not change with flying distance, include expenses for landing, parking, security, and ground handling service charges. In contrast, variable costs, such as fuel cost, vary with the total mileage traveled.

Jet fuel is a major variable cost component in the operations of commercial airlines. Between 2004 and 2009, there were large fluctuations in jet fuel prices, with a marked three-fold increase between 2004 and 2008, followed by a rapid decline to the pre-2004 price level and then substantial increases again. Despite continuous efforts of airlines and aircraft manufacturers to enhance operation and product efficiency, what they achieved cannot match the fluctuations in jet fuel prices (Air Transport Association, 2008). In 2012, the airline fuel bill was expected to reach almost $200 billion, which was more than 30% of total operating costs (International Air Transport Association (IATA), 2012). Moreover oil will continue to represent a significant share of commodities traded because of increasing volumes, as well as expected price growth in the mid- to long-term (Airbus, 2012). This fuel price uncertainty is a major challenge facing the airline industry which has been researched, for example by Ryerson and Hansen (2010), who

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[1] Calculations made by Kupfer et al. (2012a) using data from the International Civil Aviation Organization (ICAO) and the United Nations Conference on Trade and Development (UNCTAD).

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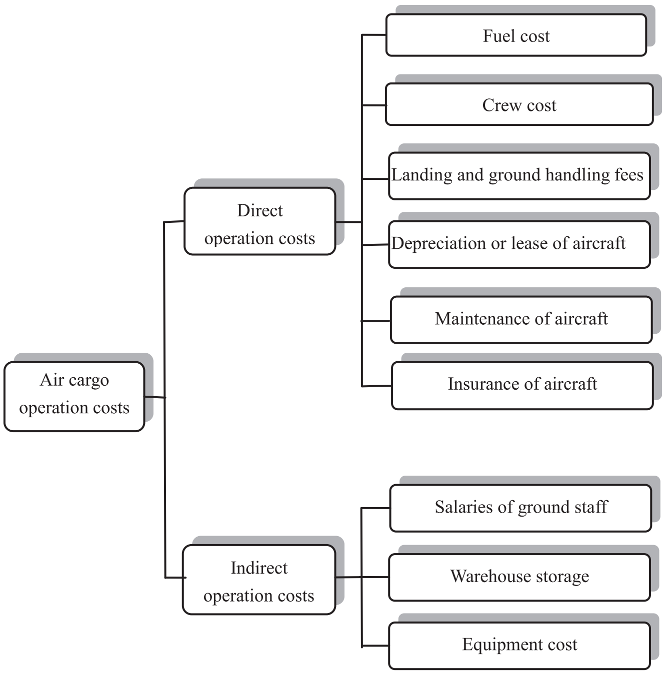

Fig. 1. Different types of air cargo operation costs.

evaluated the operation costs and passenger preference costs for different aircraft types over a range of fuel prices and route distances to determine the minimum cost for a fleet mix.

With growing development in air cargo transportation, there has been increasing research in this area but little has been done to explore the costs involved in different stages of operations in air cargo transportation. These costs include front- and rear-end operation costs, air cargo terminal cost, ground handling cost, airport service and equipment costs, as well as flight cost. This study proposes a model for examining the effects of fluctuations in jet fuel price on the cost of air cargo transport and the choice of freighters with different load capacities for different routes. Cost functions are formulated for different air cargo transport operations with variables including route distance, aircraft size and type, and airport charges. Not only can the cost functions reveal the impact of fuel price fluctuations on different aspects of air cargo transport, they can also assist airlines in selecting the aircraft type with the best fuel economy for different route distances and cargo volumes. A case analysis is performed with four air cargo traffic routes and eight aircraft types to validate the applicability of the formulated model.

The remainder of the paper is organized as follows. Section 2 describes the model formulation for air cargo transport cost functions. Section 3 validates the developed model and presents its applications. Conclusions drawn from the cost analyses and suggestions for future research are included in Section 4.

2. Model formulation

In this study, cost functions for the air cargo transport process, excluding road transport, are developed. From the shipper to the consignee, different operations are involved and respective costs are incurred. These costs include front- and rear-end operation costs, air cargo terminal cost, aircraft ground handling cost, airport service and equipment costs, and flight cost. Functions for these costs are established using mathematical modeling and are described as follows.

2.1. Front- and rear-end operation costs

Front- and rear-end operation costs include expenses for packaging and handling of shipments, document handling, Electronic Data Interchange, and so on, which are charged depending on the nature of the consignment and as a lump sum for the entire consignment. Hence, on average, the greater the cargo weight, the lower the front- and rear-end operation costs per kilogram. Let D_{mn} represent the front- and rear-end operation costs per kilogram of cargo transported from the departure airport m to the destination airport n, and the related cost function can be formulated as:

$$D_{mn} = (V_m + V_n)/q \tag{1}$$

where V_m and V_n denote related front- and rear-end operation charges per batch at airports m and n, respectively; and q represents the weight per batch of cargo.

2.2. Air cargo terminal cost

Costs incurred at the air cargo terminal include expenses paid for warehouse storage, container freight station (CFS) handling, and customs clearance. The total customs clearance fee comprises a goods examination fee; a quarantine inspection fee for agricultural, animal, and fishery products; and a fixed charge for customs clearance. Let A_{mn} represent the air cargo terminal cost per kilogram of cargo transported from departure airport m to destination airport n, and the related cost function can be formulated as:

$$A_{mn} = (B_m t_m + X_m) + (B_n t_n + X_n) \tag{2}$$

where B_m and B_n represents the storage cost per kilogram of cargo, t_m and t_n denote the average number of days the cargo is stored at the warehouse, and X_m and X_n are the handling and customs clearance fees per kilogram of cargo at airports m and n, respectively.

2.3. Aircraft ground handling cost

Prior to take-off from the departure airport, cargo containers need to be loaded onto the freighter aircraft and the aircraft require pushback or towing and guidance into position. The costs incurred for using the facilities for handling these operations vary with the type of aircraft. Let E^f_{mn} represent the aircraft ground handling cost per kilogram of cargo transported on aircraft type f from departure airport m to destination airport n, and the related cost function can be formulated as:

$$E^f_{mn} = F^f_m + \left[(Q_m + Q_n)e^f\right] \Big/ \rho^f_{mn} l^f_{mn} \tag{3}$$

where F^f_m denotes the pushback or towing cost for aircraft type f at the departure airport m. Let Q_m and Q_n represent the cost for loading and unloading each cargo container at airports m and n, respectively. e^f is the average number of containers that can be loaded onto aircraft type f. Let ρ^f_{mn} and l^f_{mn} represent the average load factor and load capacity of aircraft type f from departure airport m to destination airport n, respectively.

2.4. Airport service and equipment costs

Fees are paid by airlines for using the services and facilities at airports. Examples of such fees are landing charges for use of the runway and parking, terminal charges for use of the airport infrastructure, security charges, noise charges for protection of the environment, and air traffic control charges for en route navigation.

The type and amount of charges levied vary with airports. In this study, airport charges are divided into two categories. One refers to those calculated according to the length of stay, such as parking charges; while the other includes those calculated according to aircraft type, such as landing, noise, and security charges. Let U^f_{mn} represent the airport service and equipment costs per kilogram of cargo transported on aircraft type f from departure airport m to destination airport n, and the related cost function can be formulated as:

$$U^f_{mn} = \left[\left(K_m W^f_m + N^f_m\right) + \left(K_n W^f_n + N^f_n\right)\right] \Big/ \rho^f_{mn} l^f_{mn} \quad (4)$$

where K_m and K_n represent the parking charge per hour, w^f_m and w^f_n denote the average length of stay for aircraft type f, N^f_m and N^f_n stand for landing, noise, and security charges for aircraft type f at airports m and n, respectively.

2.5. Flight costs

Flight costs refer to expenses for aircraft operation and maintenance, fuel, and crew. Let T^f_{mn} represent the flight cost per kilometer per kilogram of cargo transported on aircraft type f from departure airport m to destination airport n, and the related cost function can be formulated as:

$$T^f_{mn} = Z^f + O^f_{mn} + R^f \quad (5)$$

where Z^f and R^f represent aircraft operation and maintenance costs and crew cost, respectively, per kilometer per kilogram of cargo transported on aircraft type f, and O^f_{mn} denotes the fuel cost per kilometer per kilogram of cargo transported on aircraft type f from departure airport m to destination airport n.

Aircraft operation and maintenance costs refer to all related expenses for using aircraft type f. These expenses include the cost for purchasing or leasing the aircraft, aircraft hull insurance premium, and maintenance fees. Purchased aircraft further incur depreciation costs. The amount of premium paid is dependent on the aircraft type, service age, and condition; and is calculated according to the purchase price. Hence, Z^f denotes the aircraft operation and maintenance costs per kilometer per kilogram of cargo transported on aircraft type f and can be expressed as:

$$Z^f = \left[\frac{p^f - r^f}{u^f} + p^f b^f + M^f\right] \Big/ \left(\theta^f \times 365 \times 24 \times S^f \times \rho^f l^f\right) \quad (6)$$

where p^f, r^f, u^f, b^f and M^f denote the purchase price, residual value, service age, premium rate, and maintenance expenses, respectively, for aircraft type f. Let θ^f represents the average utilization rate of aircraft type f (%), S^f is its speed per hour, and $\rho^f l^f$ is its average load volume of various routes for aircraft type f.

Fuel cost is determined mainly by the flight distance between departure and destination airports and the fuel consumption of the aircraft type used. Moreover, the fuel consumed varies with flight phases: climb, cruise, and descent. Hence, O^f_{mn} denotes the fuel cost per kilometer per kilogram of cargo transported on aircraft type f from departure airport m to destination airport n and can be expressed as:

$$O^f_{mn} = \left[\left(\lambda^f + \phi^f \times d_{mn}\right) \times o_m\right] \Big/ \left(\rho^f_{mn} l^f_{mn} \times d_{mn}\right) \quad (7)$$

where λ^f denotes the fuel consumption of aircraft type f during climb and decent, ϕ^f represents the fuel consumption of aircraft type f when cruising, d_{mn} is the flight distance between departure airport m and destination airport n, and o_m is fuel price per gallon.

Table 1
Costs for different air cargo transport operations on different routes (aircraft B747-400F).

Costs	TPE–HKG	TPE–SIN	TPE–SYD	TPE–LAX
Front- and rear-end operation cost	3.6 (25%)	2.2 (11%)	4.5 (13%)	3.7 (8%)
Air cargo terminal cost	5.0 (34%)	4.3 (22%)	3.7 (11%)	4.1 (9%)
Aircraft ground handling cost	0.9 (6%)	0.8 (4%)	0.7 (2%)	0.7 (2%)
Airport service and equipment cost	1.2 (8%)	1.0 (5%)	0.7 (2%)	0.9 (2%)
Flight cost				
Aircraft operation & maintenance and crew	0.6 (4%)	2.3 (12%)	5.2 (16%)	7.9 (18%)
Fuel cost	3.3 (23%)	9.1 (46%)	18.7 (56%)	27.4 (61%)
Total	14.5	19.8	33.5	44.7

Note: unit: NT$/kg, NT$1 ≅ US$0.0317; values in parentheses denote percentage of total operation cost.

For cargo freighters, the crew cost comprises mainly the annual salary of the pilot and the copilot; hence, R^f denotes crew cost per kilometer per kilogram of cargo transported on aircraft type f and can be expressed as:

$$R^f = \varsigma^f \Big/ \left(W^f \times S^f \times \rho^f l^f\right) \quad (8)$$

where ς^f the sum of the average annual salaries of the pilot and the copilot flying aircraft type f, and W^f is the average number of hours the pilot and the copilot fly aircraft type f per year.

3. Model validation and application

To validate the applicability of the cost functions developed, a case analysis is performed using actual data. Maximum taxi weight, maximum take-off weight, loading capacity, average speed, average fuel consumption, maintenance charges, annual salary of pilots, purchase price, and related operation data of various aircraft types were collected from the websites of Boeing, Airbus, and AZ Freighters in 2010. Airport charges, such as landing, noise, parking, security, and aircraft ground handling charges were obtained from websites of the studied airports in 2010 and the Global Airport Benchmarking Report 2007 published by Air Transport Research Society (ATRS, 2008). Taking into consideration variables including flight distance, aircraft type (see Appendix A for details) and airport charges (see Appendix B for details), this analysis derives the costs involved in different air cargo transport operations and examines how fluctuations in fuel price affect the respective cost categories. Results of the analysis can assist airlines in achieving cost minimization through optimal selection of aircraft, flight schedules, and cargo volume transported.

Four air cargo traffic routes from Taiwan (TPE) to Hong Kong (HKG), Singapore (SIN), Sydney (SYD), and Los Angeles (LAX) were used in the case study. The flight distances on these four routes are 812, 3253, 7260, and 10,897 km, respectively.[2] The eight types of aircraft considered included large-sized freighters such as Boeing B747-400F, MD-11F, and DC-10-30F; and medium- and small-sized freighters such as A330-200F, B767-300F, A300-600F, B757-200F, and B737-300F. This study adopted the fuel price of NT$77.6 per gallon as announced on the website of the Taiwan Chinese Petroleum Corporation in April 2010.[3]

[2] The flight distances were obtained from Discount Travel. Available at: http://www.etn.nl/distance.htm.

[3] The average price for Brent crude oil was US$84.8 per barrel in April 2010 (NT$1 ≅ US$0.0317).

3.1. Cost analysis of different air cargo operations

Table 1 displays the costs for different air cargo transport operations derived using actual data for B747-400 aircraft on the four different routes. As can be seen, flight cost, which comprises costs for aircraft operation and maintenance, crew, as well as fuel, is the only cost category that varies with flight distance. There exists a linear relationship between flight cost and flight distance; that is as expected, the longer the flight distance the higher the flight cost. Fuel cost accounts for the largest proportion of air cargo transport operation cost for medium- and long-range routes, such as TPE–SIN (46%), TPE–SYD (56%), and TPE–LAX (61%) with the proportion increasing with greater mileage traveled. In contrast, the other four cost categories are mainly determined by airport charges regardless of flight distance. As expected, the percentages of these costs categories decrease with increasing flight distance, with fuel cost accounting for an increasing proportion of total operation cost.

3.2. Optimal freighters for different routes

When determining the optimal number of freighters to deploy, profit must be a major consideration and in this study, an airline's profit is measured by its total revenue (load volume multiplied by freight charge per kilogram) minus total operation cost. The optimal payload of an aircraft type for various routes refers to the load volume of an aircraft type that brings the highest profit. Taking the TPE–HKG route, for example, the freight rate is NT$21/kg (including a fuel surcharge of NT$11). For load volumes ranging between 46,411 kg and 63,982 kg, using B767-300F aircraft for air cargo transport would yield maximum profitability. As for load volumes smaller than 46,411 kg, a smaller aircraft is required while for load volumes larger than 63,982 kg, a larger aircraft is needed. Hence, the optimal payload of a B767-300F on the TPE–HKG route ranges from 46,411 kg to 63,982 kg (see Fig. 2).

Fig. 2 shows the profit and optimal payload for different aircraft types on the TPE–SIN and TPE–HKG routes. On the TPE–SIN route, the freight rate is NT$36/kg (including a fuel surcharge of NT$11). According to the information derived, the figures can serve as useful references for airlines in their choice of freighters for profit maximization. For instance, for a cargo volume of 30,219 kg on both routes, using 737-300F aircraft is the most optimal, while A330-200F aircraft are best suited for cargo volumes ranging between 61,208 kg and 80,030 kg on the TPE–SIN route and between 63,982 kg and 83,995 kg on the TPE–HKG route. 747-400F aircraft can bring in the highest profit for large cargo volumes exceeding

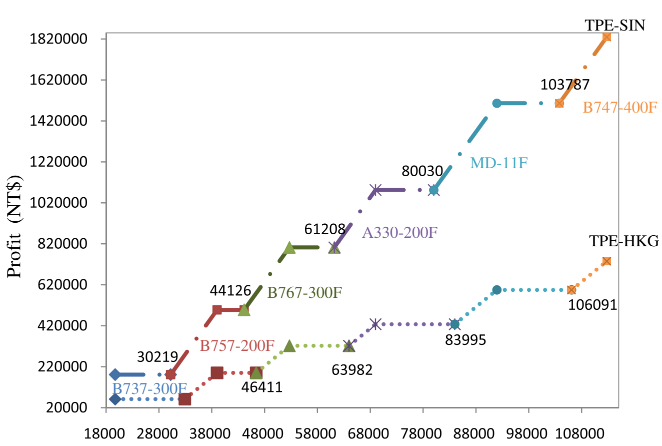

Fig. 2. Profit and optimal payload for different aircraft types on TPE–SIN and TPE–HKG routes.

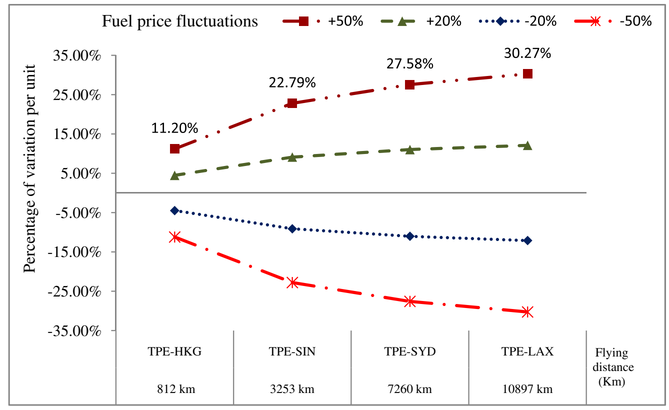

Fig. 3. Variations in total operation cost with fuel price fluctuations on different routes (B747-400F).

103,787 kg on the TPE–SIN route and 106,091 kg on the TPE–HKG route. Again, economies of scale can be observed for longer flight distances with the optimal payload for the TPE–SIN route being lower than that on the TPE–HKG route.

3.3. Effect of fuel price fluctuations on total operation cost

Fig. 3 shows variations in total operation cost with fuel price fluctuations on different routes. As expected, fuel price fluctuations and variations in total operation cost show the same trend; that is, an increase (decrease) in fuel price leads to a rise (fall) in total operation cost. Moreover, the extent of variation increases with flight distance. In other words, for the same percentage of increase (decrease) in fuel price, routes with longer flight distance will have a larger increase (decrease) in total operation cost.

3.4. Effect of fuel price fluctuations on optimal payload

To ameliorate the effect of fuel price fluctuations on operation costs of airlines, a fuel surcharge is included in the freight rate. The surcharge varies in proportion to the changes in fuel price. Again, using the example in Section 3.3, for the TPE–HKG route, the fuel surcharge included in the freight rate of NT$21/kg is NT$11. With a 50% increase in fuel price, the fuel surcharge on this route would become NT$16.5, driving the freight rate up to NT$26.5. Fig. 4 shows variations in profit and optimal payload for different aircraft types with fuel price fluctuations, which are reflected totally in freight rate. In other words, changes in fuel price are met with corresponding adjustments in freight rate with fuel surcharge

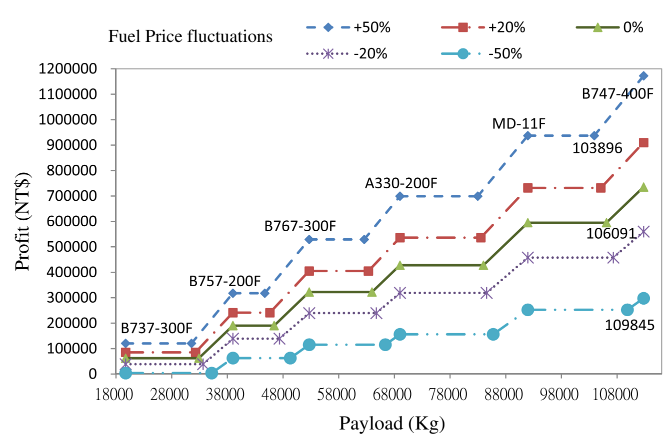

Fig. 4. Profit and optimal payload for different aircraft types with adjustment in freight rate (TPE–HKG).

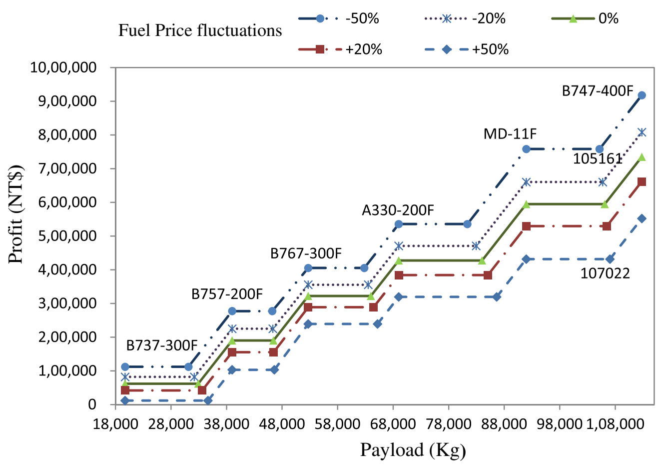

Fig. 5. Profit and optimal payload for different aircraft types without adjustment in freight rate (TPE–HKG).

included. As can be seen, with a 50% increase in fuel price, the optimal payload for B747-400F aircraft drops from 106,091 kg to 103,986 kg. As mentioned above, the freight rate increases with a rise in fuel price due to the corresponding increase in the fuel surcharge, thus bringing in higher total revenue. When the increase in total revenue exceeds the rise in fuel cost, the optimal payload will drop, resulting in profit being generated even for the same aircraft with smaller cargo volumes.

On the other hand, with a 50% decrease in fuel price, the optimal payload rises to 109,845 kg. Similar trends of increases and decreases in optimal payloads are observed for other aircraft types. Such observations have important implications for deployment of air freighters. When fuel prices rise and the optimal payloads for various aircraft types drop accordingly, airlines can make greater profits when using the same aircraft for smaller cargo volumes. On the contrary, when fuel prices drop, and optimal payloads for various aircraft types rise accordingly, the deployment of the same aircraft requires a larger cargo volume to maintain revenue.

In a situation where immediate adjustment of freight rate in response to fuel price fluctuations cannot be made, changes in total operation cost will be borne entirely by the airline, which, in turn, would affect its profit. Fig. 5 shows the profit and optimal payload for different aircraft types in such a scenario. As can be seen, with a 50% increase in fuel price but no corresponding change in freight rate, the profit will decrease and the optimal payload for B747-400F aircraft rises from 106,091 kg to 107,022 kg. Such changes imply that a large cargo volume would be required for large aircraft in order to maintain a profit. On the other hand, with a 50% decrease in fuel price but no corresponding change in freight rate, profit will increase and the optimal payload for B747-400F aircraft drops to 105,161 kg. Similar trends in increases and decreases in optimal payloads are observed for other aircraft types. When fuel prices rise and the optimal payloads for various aircraft types rise accordingly, airlines can make a higher profit when using the same aircraft for larger cargo volumes. On the contrary, when fuel prices drop, the optimal payloads for various aircraft types drop accordingly.

4. Conclusions and suggestions

In this study, a model was developed with cost functions formulated for different stages of cargo transport operation. An empirical analysis was performed with actual data from four air cargo traffic routes and eight aircraft types to validate the applicability of the model and to examine the effects of fuel price fluctuations on different cost categories and the optimal payloads for different aircraft types. The results obtained reveal that as expected fuel price fluctuations lead to an increase in total operation cost for all flight routes and aircraft types with the impact being more significant for routes with longer flight distances and aircraft of larger size.

The choice of freighter in the face of fuel price fluctuations would depend on whether the changes in fuel price can be matched with corresponding changes in freight charge. In the case of a rise in fuel price that is matched with a corresponding increase in freight rate, the optimal payloads for various aircraft types drop and airlines can make a higher profit when using the same aircraft for smaller cargo volumes. In contrast, when an increase in fuel price cannot be matched with a corresponding increase in freight rate, optimal payloads for various aircraft types rise. This means that larger cargo volumes are required for the aircraft types to maintain a profit.

This research focuses on air cargo transport using cargo freighters. Future studies could explore the impact of fuel price fluctuations on operation costs of combi-aircraft that provide both passenger and cargo transport. In addition, the four routes examined in this study cover only the Asia-Pacific region and Los Angeles. Routes to other American and European cities should also be included in the investigation for comparison. Furthermore this study focuses on the effect of fuel price fluctuations on the supply side, rather than the demand side, of air cargo transport. Future research could explore the effects of fluctuations in fuel prices on air cargo demand and revenue generation.

Appendix A. Details of aircraft

	B747-400F	MD-11F	DC-10-30F	A330-200F	B767-300F	A300-600F	B757-200F	B737-300F
Maximum taxi weight[a] (kg)	364,235	274,655	264,444	227,900[b]	187,334	171,400[b]	116,100	56,700
Maximum take-off weight[a] (kg)	362,873	273,294	263,083	227,000[b]	186,880	170,500[b]	115,650	56,473
Loading capacity[a] (kg)	112,763	91,962	80,512	69,000[b]	52,700	48,100[b]	39,000	19,731
Average speed[a] (km/h)	967	946	965	871[b]	850	871[b]	870	820
Average fuel consumption[a] (gallon/km)	3.4346	3.0786	2.7386	2.0267[b]	1.5574	1.5199[b]	1.6277	0.9382
Maintenance charge[c] (NT dollar/year)	13,916,295	6,198,014	5,554,824	6,652,620	9,063,133	4,051,983	3,800,669	2,894,355
Annual salaries of pilots[c] (NT dollar/year)	5,048,064	4,795,661	4,543,258	4,290,854	4,038,451	3,786,048	3,786,048	3,533,645
Purchase price[a] (million NT dollar/frame)	7516	3347	3000	5703[b]	4895	3474[b]	2053	1563

[a] http://www.boeing.com/.
[b] http://www.airbus.com/.
[c] http://www.azfreighters.com/planes/.

Appendix B. Airport charges for different aircraft types and terminal charges

Airport	B747-400F	MD-11F	DC-10-30F	A330-200F	B767-300F	A300-600F	B757-200F	B737-200F	All types	All types
	Landing charges[a] (includes noise charge)								Security[a]	Storage[b]
TPE	98,708	74,513	71,978	57,742	47,512	43,369	26,928	13,620	3218	1.50
HKG	99,054	75,577	72,901	63,444	52,930	48,637	34,262	18,752	3626	1.69
SIN	84,230	62,521	60,046	51,190	41,360	37,498	24,097	10,801	2750	1.28
SYD	53,484	40,281	38,776	33,458	27,545	25,130	17,046	8324	1852	0.86
LAX	68,266	52,317	47,431	44,885	32,824	33,748	23,159	12,848	2455	1.14
	Parking charges[c]								Front-operation[d]	Rear-end operation[d]
TPE	5443	1500	1250	3405	2803	2558	1735	1581	1500	1250
HKG	4942	1680	1420	4942	4942	4942	4942	4942	1680	1420
SIN	5070	1280	1150	3951	2918	2708	2239	1131	1280	1150
SYD	2129	950	850	2129	2129	2129	2129	2129	950	850
LAX	8128	1150	1050	5319	3870	3981	2709	1471	1150	1050
	Aircraft ground handling charges[a]								Customs clearance[d]	Container Loading[e]
TPE	24,490	21,810	21,810	21,810	14,700	14,700	14,700	9,740	1250	490
HKG	27,594	25,667	25,667	25,667	16,563	16,563	16,563	10,975	1408	550
SIN	20,927	19,466	19,466	19,466	12,561	12,561	12,561	8323	1068	420
SYD	14,094	13,110	13,110	13,110	8460	8460	8460	5606	720	280
LAX	18,681	17,376	17,376	17,376	11,213	11,213	11,213	7430	953	372

[a] Unit: NT$/Flight.
[b] Unit: NT$/kg-day.
[c] Parking charge for 3 h.
[d] Unit: NT$/Batch.
[e] Unit: NT$/Container.

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