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A study on airlines' differentiated cargo service strategies

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ABSTRACT

This study analyzes how an airline operates differentiated cargo services to meet shipping demand for different goods so as to enhance its service level, air freight demand, and total profit. The shipping alternative choice model assumes shippers with different demand characteristics choose the alternative with the lowest transportation and inventory costs between express and standard shipping services offered by different airlines. The study then formulates airline cost functions with respect to providing standard and express services. Furthermore, the study explores demand–supply interactions and constructs a mathematical programming model to determine flight frequencies and shipping charges for standard and express services by maximizing the object airline's total profit. The results show that those shipping high-value freights tend to select express shipping services and, for the object airline, operating differentiated cargo services rather than the current standard services can raise its market share and total profit by 19.4% and 8.6%, respectively. Moreover, for perishable goods stored in lower temperature-control devices, the charges should be higher. The results also show that not only airlines, but also shippers, can markedly reduce their costs and enhance their competitive advantages with express shipping services.

1. Introduction

In recent years, shipping demands for electronic and fresh cargos have continually increased due to fast-growing international trade and high-tech industries. To efficiently deliver high-value or short shelf-life cargos to foreign countries, shippers choose air transportation as the main transport mode. According to the Boeing World Air Cargo Forecast Team (2010), international express expanded from 4.1% of total international air cargo traffic in 1992 to 12.8% in 2008. Furthermore, because the decline in international express flows in 2009 was about the same magnitude as the drop in the overall world air cargo market, international express maintained its share at about 12.6% of total traffic. As businesses continue to expand beyond domestic or nearby regional markets, the international express sector will continue to grow. In practice, airlines work to reduce transit times and enhance service levels in order to attract valuable, time-sensitive cargos. In addition, some airlines provide differentiated services and charges for cargos with different characteristics. For example, Japan Airlines Cargo (2012) provides a time definite service, J SPEED, to support customers by making transportation, production, and inventory planning more efficient. Air France (2012) provides service with the fastest possible airport-to-airport solution; personal, dedicated attention; simple administrative procedures; and no booking required. Aerolineas Argentinas (2012) provides express service from the moment the cargo is dispatched to ensure cargo is delivered on the same day or at the first hour of the following day.

In recent years, many studies have focused on air express services. Jung (1992, 1993) studied strategies for developing international express delivery services but focused on the home delivery market. Lin et al. (2003) compared the economic effects of hub and spoke networks with center-to-center directs on a carrier's air express operations. Park et al. (2009) explored the relative importance of factors that influence the adoption of an air express delivery service, and evaluated the competitiveness of air cargo express carriers in the Korean market. In spite of all this research activity, few studies constructed models related to issues investigated in this study. This study attempts to construct a demand–supply interaction model to analyze the relationships between air cargo carriers' differentiated service strategies and shippers' demands. The model not only determines whether airlines should provide differentiated cargo services in response to cargos with various demand characteristics but also determines the optimal aircraft type, flight frequencies, and shipping charges for differentiated services by maximizing profits.

Flight frequency has dramatic influence on both airlines' operation costs and revenue. The greater the flight frequency, the higher the service level the carrier offers and the more shipping volume it can attract. The greater the flight frequency, the higher the total capacity of the flights and lower the capacity utilization. Therefore, when airlines offer increased flight frequency, the operation cost per unit-weight increases and profit per unit-weight decreases. Airlines strive to maximize operation

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Nomenclature

x	alternative airlines
m	object airline
q_{ktc}^{rs}	amount of goods that shipper k uses airline x to ship from r to s at time t
P^{xrs}	unit charge of airline x for standard service on link rs
$P^{xrs'}$	unit charge of airline x to provide express service on link rs
P_l^{xrs}	unit charges of airline x to provide temperature-control service for temperature-range l goods for standard service goods on link rs
$P_l^{xrs'}$	unit charges of airline x to provide temperature-control service for temperature-range l goods for express service goods on link rs
F_h^{xrs}	flight frequencies that airline x provides for standard service on link rs with aircraft type h
$F_h^{xrs'}$	flight frequencies that airline x provides for express service on link rs with aircraft type h
θ	length of entire study time
I^{xrs}	intervals between flights that airline x provides on link rs for standard services
$I^{xrs'}$	intervals between flights that airline x provides on link rs for express services
f^{xrs}	last flight for standard services
$f^{xrs'}$	last flight for express services
t_i^{xrs}	take-off time for the ith flight by airline x on link rs with standard services
$t_i^{xrs'}$	take-off time for the ith flight by airline x on link rs with express services
T_{kc}^{x1}	operation times for standard services before the take-off time of the flight for good c of shipper k
$T_{kc}^{x1'}$	operation times for express services before the take-off time of the flight for good c of shipper k
T_{ktc}^{x}	waiting times for good c of shipper k using standard services of airline x at time t at the origin airport
$T_{ktc}^{x'}$	waiting times for good c of shipper k using express services of airline x at time t at the origin airport
T_{kc}^{x2}	handling times for standard services at the destination airport
$T_{kc}^{x2'}$	handling times for express services at the destination airport
T^{xrs}	transit times of airline x on link rs for standard service
$T^{xrs'}$	transit times of airline x on link rs for express service
V_c	unit value of good c
R_c	decay rate of good c per day
$D_k(\cdot)$	decay cumulative distribution functions for the entire shipping process for standard services
$D'_k(\cdot)$	decay cumulative distribution functions for the entire shipping process for express services

$$\mu^m = \begin{cases} 1, & \text{if a shipper chooses airline } m \text{ to transport by standard service for normal goods without temperature control} \\ 0, & \text{otherwise} \end{cases}$$

$$\mu^{m}{}' = \begin{cases} 1, & \text{if a shipper chooses airline } m \text{ to transport by express service for normal goods without temperature control} \\ 0, & \text{otherwise} \end{cases}$$

Q^{mrs}	total normal cargo amounts that object airline m on link rs for standard services
$Q^{mrs'}$	total normal cargo amounts that object airline m on link rs for express services
Q_l^{mrs}	total temperature-range l cargo amounts that object airline m on link rs for standard services
$Q_l^{mrs'}$	total temperature-range l cargo amounts that object airline m on link rs for express services
α_h	airport user fee for aircraft type h
α_h^1	variable cost per unit distance for aircraft type h
d^a	distance of flight a.

$$\tau_h^{r,s,a} = \begin{cases} 1, & \text{if aircraft } h \text{ is used to serve flight } a \text{ transporting goods from } r \text{ to } s \text{ with standard service} \\ 0, & \text{otherwise} \end{cases}$$

$$\tau_h^{r,s,a}{}' = \begin{cases} 1, & \text{if aircraft } h \text{ is used to serve flight } a \text{ transporting goods from } r \text{ to } s \text{ with express service} \\ 0, & \text{otherwise} \end{cases}$$

λ	unit cost per kilogram
q_{1ktc}^{rs}	number of cold cabinets that packed goods c of shipper k from r to s at time t
δ	average loading volume for one cold cabinet
G_l	fixed cost per unit time for using a cold cabinet of range l
g_l	energy cost per unit time for using a cold cabinet of range l
E^{rs}	extra cost for providing high handling priority on link rs
C^{rs}	airline's total operation costs for standard services
$C^{rs'}$	airline's total operation costs for express services
P^{mrs}	shipping charges for normal goods using standard services
$P^{mrs'}$	shipping charges for normal goods using express services
S_h	capacity of aircraft type h
U_h	capacity utilization of aircraft type h

profit while shippers are concerned about cargo delivery times, which influence their inventory costs. Airlines may use increased flight frequencies with smaller aircraft to attract shipping volume, but excessive frequencies may result in diseconomies of scale. The significant interaction between demand and supply necessitates the use of a programming model to determine optimal flight frequencies and function of the type of planes used. On the other hand, low flight frequency results in more shipments during longer shipping cycles and gains the economies of using larger aircraft; however, that may reduce the carriers' service level and increase the shippers' cargo waiting time for a flight. In such a situation, carriers may lose their customers and market advantages. The above processes involve a trade-off between shipping demands and carriers' operation costs, and that trade-off may differ between standard shipping service for general cargos and express service for time-sensitive cargos.

The shipping alternatives considered in this study include the two shipping services noted above provided by various air carriers. Standard shipping service has lower flight frequency and a lower shipping charge. Express shipping service has greater cargo handling priority at airports, more frequent flights, and higher shipping charges. Temperature-control service is usually provided for perishable cargos to ensure quality. This study constructs a shipping alternative choice model by assuming shippers choose the alternative with the lowest transportation and inventory costs. The study formulates airlines' cost functions with respect to providing standard and express services. Furthermore, the study explores demand–supply interactions and constructs a mathematical programming model to determine flight frequencies and shipping charges for standard and express services by maximizing the object airline's total profit. In response to markets with various distinct cargos, the study also examines optimal combinations of standard, express, and temperature-control services that make airlines operate most profitably.

The remainder of this paper is organized as follows. Section 2 illustrates differentiated services and formulates the shippers' alternative choice model and airlines' cost functions. The airline's profit function and strategy planning model are formulated in Section 3. In Section 4, an example is presented to demonstrate the application of the model. Finally, Section 5 presents conclusions and suggestions for future studies.

2. Model

This study constructs the model from both demand and supply perspectives. On the demand side, this study assumes shippers choose the optimal shipping alternative by minimizing the sum of transportation and inventory costs. On the supply side, this study recognizes there is competition among air cargo carriers and assumes carriers determine flight frequencies and shipping charges for differentiated services and various temperature-range cargos by maximizing their own profits, taking into account the interaction between shippers' demands and carriers' charges and service levels.

2.1. Carriers' shipping strategies

In order to reduce transit time and provide high quality service, air cargo carriers may provide differentiated shipping services, thereby attracting cargos with various characteristics. The shipping strategies discussed in this study include standard service and express service, which are illustrated as follows.

2.1.1. Standard shipping service

For O–D pairs with moderate or low shipping demand, carriers may plan low-frequency flights and ship cargos via more than one intermediate airport. In such a way, carriers can use large aircraft to realize economies of aircraft size and raise load factors by accumulating and consolidating shipments at various times and locations. Such services are commonly used and referred to as standard services in this study. The shipping charge per unit weight can be lower, thereby attracting more shipping demand for price-sensitive cargos. Nevertheless, longer transit time also increases shippers' inventory costs; shippers whose goods are perishable, high-value, and time-sensitive are less likely to choose this strategy if there are alternative services, such as express and temperature control.

2.1.2. Express shipping service

Express shipping service provides higher flight frequency, more direct flights, and greater handling priority at airports, as compared with standard service. Such services reduce transit time but increase carriers' operation costs. Therefore, the shipping charge for express service should be higher due to greater flight frequency and the extra cost of providing priority service. Using express services, shippers with time-sensitive cargos might spend more on transportation costs, but their inventory costs simultaneously decrease. Fig. 1 illustrates generalized cost conflict between inventory and transportation costs (Ballou, 2004). Therefore, the probability that shippers choose express service increases when their goods are perishable, time-sensitive, and/or valuable.

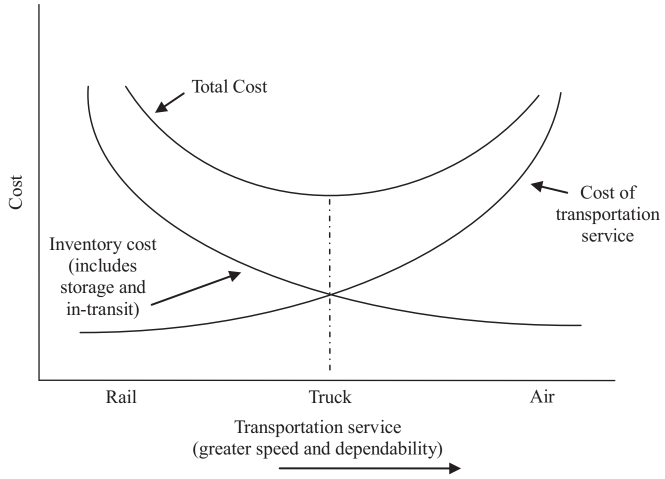

Fig. 1. Generalized cost conflict between transportation and inventory costs as a function of transportation service characteristics (Ballou, 2004).

Furthermore, airlines provide temperature-control services for perishable cargos. Perishable goods are put in a temperature-controlled space, such as a freezer room at the terminal and a cold container during the flight, thereby minimizing the probability that goods perish.

2.2. Shippers' shipping costs

For competitive international trade in practice, buyers may be willing to pay more when they have emergent demand. Therefore, length of transit time is an important issue for sellers (i.e., shippers) to consign their goods with buyers and also to choose carriers. The extant literature and the opinions of managers in practice indicate that shippers choose a shipping service based on three major quantifiable factors (i.e., shipping charge, flight frequency, and transit time). Therefore, this study considered these three factors when constructing a shipping choice model. Flight frequency and transit time are both related to cargo time lost waiting for shipping and during transit, which are referred to as stationary and line-haul inventory costs. This study, thus, assumes that shippers choose the optimal shipping service that minimizes the sum of transportation and inventory costs.

2.2.1. Shippers' transportation costs

Transportation costs for standard and express service are cargo amount multiplied by unit standard charge and unit express charge, respectively. There is also a temperature-control cost if cargos need temperature control while in the terminal and during transit.

The transportation cost borne by shipper k who chooses airline x to ship cargos from r to s by standard service at time t is $q^{rs}_{ktc}P^{xrs}$, where q^{rs}_{ktc} denotes the amount of goods that shipper k uses airline x to ship from r to s by standard service at time t, and P^{xrs} represents the unit charge of airline x for standard service on link rs. On the other hand, when the shipper chooses express service, the transportation cost becomes $q^{rs}_{ktc}P^{xrs'}$, where $P^{xrs'}$ is the unit charge of airline x to provide express service on link rs. Furthermore, if cargos need temperature control while in the terminal and during transit, there exists transportation cost $q^{rs}_{ktc}P^{xrs}_{l}$ or $q^{rs}_{ktc}P^{xrs'}_{l}$ for standard and express service, respectively, where P^{xrs}_{l} and $P^{xrs'}_{l}$ are the unit charges of airline x to provide temperature-control service for temperature-range l goods for standard and express service goods on link rs, respectively.

2.2.2. Shippers' inventory cost

In this study, inventory cost is defined as an opportunity cost for goods that cannot be sold or used during the shipping process; thus, for this reason, inventory cost is dependent on the quantity and value of goods, and time spent in the shipping process. Tavasszy (2005) indicated that, once an order has been placed, the customer and the seller often want immediate delivery, and, as such, there may be a willingness to pay for this. Tavasszy (2005) presents the value of freight time obtained through Stated Preference and Revealed Preference studies and the results show that the value of freight time for air transportation is SEK117 per hour shipment. The loss or decay of cargo value during the shipping process is also included in the inventory cost. The shipping process can be divided into three parts: goods at origin airport, goods in flight (en route), and goods at destination airport, respectively.

In general, airlines assign different types of aircraft to satisfy various shipping demands on different routes. Let F_h^{xrs} and $F_h^{xrs\prime}$ be the flight frequencies that airline x provides for standard and express service on link rs with aircraft type h, respectively. Therefore, total flight frequencies provided by airline x for standard and express service from r to s are $\sum_h F_h^{xrs}$and $\sum_h F_h^{xrs\prime}$, respectively. Assume $(0,\theta)$ denotes the entire study time range, then the intervals between flights that airline x provides on link rs for standard and express services, I^{xrs} and $I^{xrs'}$, can be expressed as $\theta/\sum_h F_h^{xrs}$ and $\theta/\sum_h F_h^{xrs\prime}$, respectively. In addition, take-off time for the ith flight by airline x on link rs with standard and express services can be formulated as $t_i^{xrs}=i\cdot I^{xrs}, \quad i=1,2,\ldots,f^{xrs}$, and $t_i^{xrs\prime}=i\cdot I^{xrs'}, \quad i=1,2,\ldots,f^{xrs'}$, where f^{xrs} and $f^{xrs'}$ represent the last flight for standard and express services, respectively.

Ground services, such as cargo handling and pallet and container packing, consume a lot of time, and express services ensure goods are handled with high priority. As such, the operation time in an airport for those goods can be reduced; thus, if the goods are perishable, the probability of quality decay decreases. Let T_{kc}^{x1} and $T_{kc}^{x1\prime}$ denote the operation times for standard and express services, respectively, before the take-off time of the flight for good c of shipper k, then $T_{kc}^{x1}>T_{kc}^{x1\prime}$.

At different times t that shipper k's goods arrive at the airport, waiting times and inventory costs of goods c vary and also differ between standard and express services. Let T_{ktc}^{x} and $T_{kc}^{x\prime}$ represent the waiting times for good c of shipper k using standard and express services, respectively, of airline x at time t at the origin airport. Length of waiting time is related to both the time that goods arrive at the airport and operation time, T_{kc}^{x1} and $T_{kc}^{x1\prime}$, hence, the waiting times T_{ktc}^{x} and $T_{kc}^{x\prime}$ can be formulated as

$$T_{ktc}^{x}=\begin{cases} t_i^{xrs}-t, \quad t\in[t_{i-1}^{xrs},\left(t_i^{xrs}-T_{kc}^{x1}\right)] \\ t_i^{xrs}+\left(\left\lceil\frac{T_{kc}^{x1}-(t_i^{xrs}-t)}{I^{xrs}}\right\rceil^{+}\cdot I^{xrs}\right)-t, \quad t\in\left(\left(t_i^{xrs}-T_{kc}^{x1}\right),t_i^{xrs}\right], \quad \forall rs \end{cases} \tag{1}$$

$$T_{ktc}^{x\prime}=\begin{cases} t_i^{xrs\prime}-t, \quad t\in[t_{i-1}^{xrs\prime},\left(t_i^{xrs\prime}-T_{kc}^{x1\prime}\right)] \\ t_i^{xrs\prime}+\left(\left\lceil\frac{T_{kc}^{x1\prime}-(t_i^{xrs\prime}-t)}{I^{xrs'}}\right\rceil^{+}\cdot I^{xrs'}\right)-t, \quad t\in\left(\left(t_i^{xrs\prime}-T_{kc}^{x1\prime}\right),t_i^{xrs\prime}\right], \quad \forall rs \end{cases} \tag{2}$$

In the first row of Eq. (1), this study assumes goods arrive at the origin airport during time interval $[t_{i-1}^{xrs},(t_i^{xrs}-T_{kc}^{x1})]$, which means there is enough time to finish all processes before the nearest flight's takeoff, and the goods can arrive at the destination airport without delay. In other words, the goods should arrive at the origin airport at a time that enables airport operators to finish all related processes prior to the nearest flight takeoff. The waiting time of goods is equal to the time interval between the arrival time of the goods at origin airport and the nearest flight takeoff time. If the waiting time is not sufficient for finishing related processes, the goods are shipped on the next nearest flight after finishing the processes. In such a situation, the waiting time of goods in the airport would increase and incur delay at the destination airport, which is shown in the second row of Eq. (1). Similarly, for express service, the waiting time of goods at the origin airport is shown in Eq. (2). However, due to higher flight frequency and shorter process time with higher priority, the waiting time for express service at the origin airport must be shorter than for standard service.

Hsu et al. (2005) indicated that, when the value of goods increases, shippers tend to choose direct transportation to save inventory costs; thus, the service with lowest transit time attracts more valuable or perishable cargos for airlines. In general, airlines may provide various services, such as direct flights, stopping along the way, and transferring between flights for different O–D cargos. For cargos shipped with direct flights, carriers' inventory costs include only stationary inventory costs at origin and destination airports, and a line-haul inventory cost during the flight. For cargos shipped on a flight with scheduled stops along the route to the final destination, the line-haul inventory cost includes the cost for stopping at intermediate airports, as well as flight time.

Temperature is one of the most important factors that influences perishable cargos' quality. In general, the lower the temperature, the longer a high quality can be maintained. For shipping services with temperature control, cargos are put into cold cabinets or containers with a suitable temperature until arriving at the destination airport. This study followed Hsu et al. (2007) and assumed the decay of perishable goods could be described as a function of transit time if temperature was appropriately fixed and other influencing factors did not change.

This study assumes airlines handle goods using a normal process for standard shipping service but use a priority process for express service; thus, goods for express service should pass through customs more quickly and shippers should be able to pick up their goods earlier at the destination airport. Let T_{kc}^{x2} and $T_{kc}^{x2\prime}$ denote the handling times for standard and express services, respectively, at the destination airport. The handling time is from the flight of airline x shipping goods c for shipper k arriving at destination airport until the goods are ready to be picked up, and $T_{kc}^{x2}>T_{kc}^{x2\prime}$.

Let transit times of airline x on link rs for standard and express service be T^{xrs} and $T^{xrs'}$, respectively; the unit value of good c is V_c per unit weight, and the value of good c decreases V_cR_c per unit weight, unit time, where R_c is the decay rate of good c per unit time. Therefore, the inventory cost for consigning airline x by standard and express services can be represented as $q_{ktc}^{rs}V_cR_c(T_{ktc}^{x}+T^{xrs}+T_{kc}^{x2})$ and $q_{ktc}^{rs}V_cR_c(T_{ktc}^{x\prime}+T^{xrs'}+T_{kc}^{x2\prime})$, respectively. For perishable goods, the expected decay costs during shipping for goods c of shipper k via airline x with standard and express services are $q_{ktc}^{rs}V_cD_k(T_{ktc}^{x}+T^{xrs}+T_{kc}^{x2})$ and $q_{ktc}^{rs}V_cD_k'(T_{ktc}^{x\prime}+T^{xrs'}+T_{kc}^{x2\prime})$, respectively, where $D_k(\cdot)$ and $D_k'(\cdot)$ denote the decay cumulative distribution functions for the entire shipping process for standard and express services, respectively.

2.3. Shippers' alternative choice model

Shippers consider all alternatives in the market and choose the one with the lowest sum of transportation and inventory costs when consigning good c at time t. Therefore, the objective function of the shippers' alternative choice model for normal goods can be formulated as

$$Min\begin{cases} P^{xrs}q_{ktc}^{rs}+q_{ktc}^{rs}V_cR_c\left(T_{ktc}^{x}+T^{xrs}+T_{kc}^{x2}\right) \\ P^{xrs'}q_{ktc}^{rs}+q_{ktc}^{rs}V_cR_c\left(T_{ktc}^{x\prime}+T^{xrs'}+T_{kc}^{x2\prime}\right) \end{cases} \tag{3}$$

According to airline operations in practice, temperature-control goods and equipment can be divided into three temperature ranges: frozen (−18 °C to −25 °C), chilled (2–10 °C) and fresh (15–25 °C). Furthermore, the objective function of the shippers' alternative choice model for temperature-controlled goods can be formulated as

$$Min\begin{cases} P_l^{xrs}q_{ktc}^{rs}+q_{ktc}^{rs}V_cD_k\left(T_{ktc}^{x}+T^{xrs}+T_{kc}^{x2}\right) \\ P_l^{xrs\prime}q_{ktc}^{rs}+q_{ktc}^{rs}V_cD_k'\left(T_{ktc}^{x\prime}+T^{xrs'}+T_{kc}^{x2\prime}\right) \end{cases} \tag{4}$$

Let x be alternative airlines, m denote the object airline; if a shipper chooses airline m to transport by standard service or express service for normal goods without temperature control, $\mu^m=1$ or $\mu^{m'}=1$; otherwise, $\mu^m=0$ or $\mu^{m'}=0$; and for temperature-range l goods, $\mu_l^m=1$ or $\mu_l^{m\prime}=1$; otherwise, $\mu_l^m=0$ or $\mu_l^{m\prime}=0$. By summing the total cargo amounts of all shippers consigning to object airline m for standard and express services in each time slot t, the total normal and temperature-range l cargo amounts that object airline m on link rs for standard and express services, Q^{mrs}, $Q^{mrs'}$, Q_l^{mrs} and $Q_l^{mrs\prime}$ can be computed, respectively, as

$$Q^{mrs}=\sum_c\sum_k\sum_t\mu^m q_{ktc}^{rs},\quad \forall rs \tag{5}$$

$$Q^{mrs'}=\sum_c\sum_k\sum_t\mu^{m'} q_{ktc}^{rs},\quad \forall rs \tag{6}$$

$$Q_l^{mrs}=\sum_c\sum_k\sum_t\mu_l^m q_{ktc}^{rs},\quad \forall l,\forall rs \tag{7}$$

$$Q_l^{mrs\prime}=\sum_c\sum_k\sum_t\mu_l^{m\prime} q_{ktc}^{rs},\quad \forall l,\forall rs \tag{8}$$

2.4. Airline's cost function

This study constructs cost functions for air cargo service, including costs for aircraft, cargo handling, temperature control equipment for both services, and extra costs for express service.

2.4.1. Cost for aircraft

Transportation costs related to aircraft include airport user fees and costs for using aircraft. The airport user fee comprises landing fee, parking charge, ground service fee, security charge, etc. These costs usually depend on an aircraft's size and weight. On the other hand, costs for using aircraft include flying costs, such as fuel, crew, aircraft maintenance, and depreciation or rent. All of these costs are not only proportional to the size of aircraft but also to travel distance. Let α_h denote the airport user fee for aircraft type h and α_h^1 represents the variable cost per unit distance for aircraft type h and d^a denotes the distance of flight a.

Let $\tau_h^{r,s,a}$ and $\tau_h^{r,s,a\prime}$ be binary variables, and if aircraft h is used to serve flight a transporting goods from r to s with standard and express service, then $\tau_h^{r,s,a}=1$ and $\tau_h^{r,s,a\prime}=1$, respectively. On the other hand, if aircraft h does not serve flight a with standard and express services, then $\tau_h^{r,s,a}=0$ and $\tau_h^{r,s,a\prime}=0$, respectively, which means frequencies $F_h^{mrs}$and $F_h^{mrs\prime}$ do not exist. The direct operation costs for standard and express service on link rs of object airline m are thus $\sum_a\sum_h(\alpha_h+\alpha_h^1d^a)\tau_h^{r,s,a}F_h^{mrs},\ \ \forall rs$ and $\sum_a\sum_h(\alpha_h+\alpha_h^1d^a)\tau_h^{r,s,a\prime}F_h^{mrs\prime},\ \ \forall rs$, respectively.

In practice, airlines have to consider their operation limits when planning flight frequencies, especially for fleet capacity, which may be smaller than total shipping demand. This study focuses on long-term flight frequency planning for differentiated strategies of carriers, taking into account the interaction between shippers' demands, service levels, and airlines' operation costs. Therefore, this study assumes airlines can plan ahead and have enough aircraft for the planned flight frequencies.

2.4.2. Cost for goods handling

For the convenience of operations during transit to the destination airport, and to avoid damages, airlines usually store cargos on pallets or in cabinets. Handing costs include the costs for using pallets and containers, ground service, and loading/unloading, for which the unit cost per kilogram can be represented as λ.

2.4.3. Temperature-control equipment cost

The temperature-control cost is the cost for using cold cabinets. In practice, Air France (2012) divides the temperature of storing perishable goods into three ranges (i.e., $l=1$, 2, 3). The temperature-control cost includes fixed and variable costs, where fixed costs include depreciation, interest, maintenance cost, and rent for equipment, while the variable cost is for energy, which is in proportion to the number of cold cabinets, and also depends on temperature. The lower the temperature, the more the energy needed, thus the higher the energy cost will be.

Let q_{1ktc}^{rs} denote the number of cold cabinets that packed goods c of shipper k from r to s at time t, $\lceil q_{ktc}^{rs}/\delta\rceil^+=q_{1ktc}^{rs}$, where δ is the average loading volume for one cold cabinet. In order to simplify the model, this study uses average loading volume to calculate the number of cold cabinets required, and does not consider other properties that may affect capacity utilization.

In addition to cold cabinets, temperature-control equipment also requires some basic apparatus such as thermograph, cold accumulators (eutectic plates), or refrigerator. Let G_l and g_l denote fixed cost and energy cost per unit time for using a cold cabinet of range l. The temperature control costs for shipping perishable goods for standard and express services from r to s can be then calculated as $\sum_l\sum_k\sum_t\sum_c G_l+\mu_l^m q_{1ktc}^{rs}(T_{ktc}^m+T^{mrs}+T_{kc}^{m2})g$ and $\sum_l\sum_k\sum_t\sum_c G_l+\mu_l^{m\prime} q_{1ktc}^{rs}(T_{ktc}^{m\prime}+T^{mrs'}+T_{kc}^{m2\prime})g_l$, respectively, where the energy cost for each layer is proportional to the shipping amount.

2.4.4. Extra cost and total operation cost

Airlines need more labor and equipment costs for express service as compared to standard service; let E^{rs} denote the extra cost for providing high handling priority on link rs. Then, the airline's total operation costs for standard and express services, C^{rs} and $C^{rs'}$, can be represented, respectively, as

$$\begin{aligned} C^{rs}=&\sum_a\sum_h(\alpha_h+\alpha_h^1d^a)\tau_h^{r,s,a}F_h^{mrs}+\lambda Q^{mrs} \\ &+\sum_l\sum_k\sum_t\sum_c G_l+\mu_l^m q_{1ktc}^{rs}\left(T_{ktc}^m+T^{mrs}+T_{kc}^{m2}\right)g_l,\quad \forall rs \end{aligned} \tag{9}$$

and

$$\begin{aligned} C^{rs'}=&\sum_a\sum_h(\alpha_h+\alpha_h^1d^a)\tau_h^{r,s,a\prime}F_h^{mrs\prime}+\lambda Q^{mrs'} \\ &+\sum_l\sum_k\sum_t\sum_c G_l+\mu_l^{m\prime} q_{1ktc}^{rs}\left(T_{ktc}^{m\prime}+T^{mrs'}+T_{kc}^{m2\prime}\right)g_l+E^{mrs},\quad \forall rs \end{aligned} \tag{10}$$

3. Airline's profit function and strategy planning model

To decide the shipping charge for express service, object airline m may consider the trade-off in the differences between transportation cost and inventory cost borne by shippers for these two services. For normal cargos, the critical condition for shipper's choice can be expressed as

$$\begin{aligned} &\left(P^{mrs}q_{ktc}^{rs}+q_{ktc}^{rs}V_{co}R_c\left(T_{ktc}^m+T^{mrs}+T_{kc}^{m2}\right)\right) \\ &\quad-\left(P^{mrs'}q_{ktc}^{rs}+q_{ktc}^{rs}V_{co}R_c\left(T_{ktc}^{m\prime}+T^{\prime mrs}+T_{kc}^{m2\prime}\right)\right)=0 \end{aligned} \tag{11}$$

Therefore, by summing all the shipments of various values, volumes, and delivery times in the whole market, the critical condition for shippers' choices between two services can be ascertained to determine the discriminate charges as

$$P^{mrs'} = P^{mrs} + \left(\frac{\sum_k \sum_c \sum_t V_c R_c q_{ktc}^{rs} [(T_{ktc}^{m} - T_{ktc}^{m\prime}) + \left(T^{mrs} - T^{mrs'}\right) + \left(T_{kc}^{m2} - T_{kc}^{m2\prime}\right)]}{Q^{mrs} + Q^{mrs'}} \right), \quad \forall rs \tag{12}$$

where P^{mrs} and $P^{mrs'}$ represent the shipping charges for normal goods using standard and express services, respectively. Eq. (12) shows that the greater the time value of cargos, the higher the shipping charge. On the other hand, the shipping charge for express service would be increased for the difference in transit times between the two services.

For different temperature range cargos, this study also considers the trade-off between transportation cost (shipping charge) and inventory cost (decay cost) due to both storage temperature and transit time. Similarly, the shipping charges for temperature range l cargo can be ascertained based on the critical condition of shippers' choosing services as

$$P_l^{mrs\prime} = P_l^{mrs} + \frac{\sum_k \sum_c \sum_t V_c q_{ktc}^{rs} \left[D_k \left(T_{ktc}^{m} + T^{mrs} + T_{kc}^{m2} \right) - D_k' \left(T_{ktc}^{m\prime} + T^{mrs'} + T_{kc}^{m2\prime} \right) \right]}{Q_l^{mrs} + Q_l^{mrs\prime}}, \quad \forall rs \tag{13}$$

Eq. (13) shows that the higher the value of good per unit time, or the larger the difference in transit time between two services, or the faster the goods decay in uncontrolled temperature, the higher the discriminate shipping charge for express service for temperature-controlled cargos.

Let S_h represent the capacity of aircraft type h, and U_h denote the capacity utilization of aircraft type h. Seeking to maximize profits, the object airline's flight frequency and charge planning model for different services on O-D pair rs can be shown in the following equations:

$$\underset{F_h^{mrs}, F_h^{mrs\prime}, P^{mrs'}, P^{mrs}, P_l^{mrs} P_l^{mrs\prime}}{Max} \pi^m = P^{mrs} Q^{mre} + P^{mrs'} Q^{mrs'}$$

$$+ \sum_l P_l^{mrs} Q_l^{mrs} + \sum_l P_l^{mrs\prime} Q_l^{mrs\prime} - \sum_r \sum_s \left(C^{rs} + C^{rs'} \right) \tag{14a}$$

s.t.

$$\sum_h S_h U_h F_h^{mrs} \geq Q^{mrs} + \sum_l Q_l^{mrs}, \quad \forall rs \tag{14b}$$

$$\sum_h S_h U_h F_h^{mrs\prime} \geq Q^{mrs'} + \sum_l Q_l^{mrs\prime}, \quad \forall rs \tag{14c}$$

$$Q^{mrs} = \sum_c \sum_k \sum_t \mu^m q_{ktc}^{rs}, \quad \forall rs \tag{14d}$$

$$Q^{mrs'} = \sum_c \sum_k \sum_t \mu^{m'} q_{ktc}^{rs}, \quad \forall rs \tag{14e}$$

$$Q_l^{mrs} = \sum_c \sum_k \sum_t \mu_l^m q_{ktc}^{rs}, \quad \forall rs \tag{14f}$$

$$Q_l^{mrs\prime} = \sum_c \sum_k \sum_t \mu_l^{m\prime} q_{ktc}^{rs}, \quad \forall rs \tag{14g}$$

$$\sum_h F_h^{mrs\prime} > \sum_h F_h^{mrs}, \quad \forall rs \tag{14h}$$

$$P^{mrs'} > P^{mrs}, \quad \forall rs \tag{14i}$$

$$P_l^{mrs\prime} > P_l^{mrs}, \quad \forall rs \tag{14j}$$

$$F_h^{mrs}, F_h^{mrs\prime} \geq 0 \tag{14k}$$

$$F_h^{mrs}, F_h^{mrs\prime} \in I^+ \tag{14l}$$

Eq. (14a) represents the objective function for maximizing the airline's profit; Eqs. (14b) and (14c) indicate the total capacity of flight frequencies on O–D pair rs should not be less than the total shipping amounts for both services. Eqs. (14d) and (14e) represent total shipping amounts on O–D pair rs the object airline attracts for standard and express services, respectively. Eqs. (14f) and (14g) represent total shipping amounts on O–D pair rs the object airline attracts for standard and express services with temperature control, respectively. The decision variables $F_h^{mrs\prime}$ and F_h^{mrs} in Eq. (14h) show that the flight frequency for express service should be higher than standard service on O–D pair rs. On the other hand, the unit shipping charges for express service on O–D pair rs, $P^{mrs'}$ and $P_l^{mrs\prime}$, should be higher than those for standard service, P^{mrs} and P_l^{mrs}. Finally, Eq. (14k) shows that flight frequencies are all integers and not negative.

The decision variables for the above problem are to determine the optimal flight frequencies for express and standard services and their respective shipping charges for normal and various temperature range cargoes. First, all airlines' (the object airline as well as its competitors) flight frequencies and charges are initialized using the present values. Market demand and share for the object airline are then estimated by applying the shippers' alternative choice model and aggregating the choices of shippers in the market. Next, the object airline's flight frequencies and charges for express and standard services on individual routes are determined by applying the airline operation strategy model aimed at maximizing total profit (i.e., Eqs. (14a)–(14l)). Other competing airlines use a similar approach to estimate their market share, and their flight frequencies and charges are also determined by maximizing their profits simultaneously against the flight frequencies and airfares of the object airline. The aforementioned steps conclude the first "round" of interaction; this process then continues for several more rounds. The process continues until demand-supply equilibrium is reached. When the object airline's profit is assessed to have converged, its flight frequencies and charges are determined; when the O–D market sizes are unchanging, competitors' profit-maximizing decisions concerning frequencies and charges in the O–D market will not change in response to the object airline's determined flight frequencies and charges. In such a case, shippers' choices will not change in response to the flight frequencies and charges determined by airlines, and then the demand–supply interaction converges.

4. Numerical example

This section presents an application of the proposed model. The object airline is Eva Air, which is a privately owned Taiwanese airline that was founded in 1989. The airline is currently serving 63 destinations over four continents, excepting Africa, with 59 aircraft. The fleet includes four combi-aircraft and 17 air freighters, including B747-400 and MD-11 aircraft. The total freight tonnage and Freight Tonnage Kilometer of this airline are 793,831 and 4,882,781,461, respectively, with a load factor of 82.10%, in 2011 (Eva Air, 2012). In Taiwan, the major export routes for the majority of air cargos are from Taipei to Hong Kong, Japan, and the US, respectively. This study chose the route from Taipei (TPE) to Hong Kong (HKG) as an example to analyze whether the object airline should provide differentiated shipping services in response to changes in the volume and composition of cargos in the market. The example further applies the model and shows how to decide optimal flight frequencies and charges for express and standard services. The study collected data about

Table 1
Service properties and market shares of major airlines in Taiwan.
Source: Civil Aeronautics Administration (2006).

Airlines	China airline	Eva air	Cathay Pacific	Other airlines
Shipping charge (USD/Kg)	0.7664	0.7668	0.7790	0.7948
Shipping time (h)	1.75	1.75	2	2
Frequency (flight/week)	6	9	8	6
Aircraft type	B747-400F	B747-400F MD-11F	B747-200F B747-400F	B747-400F
Temperature control service	Yes	Yes	Yes	Yes
Handling priority	No	No	Yes	No
Market share (%)	25.1	38.4	27.3	6.2

shipping charges, transit times, and cargo flight timetables for Eva Air and other competitive airlines on the route from July to September, 2006. The shipping amounts for each kind of cargo as compiled by Taiwan Taoyuan International Airport were also used.

Table 1 shows the service properties and market shares of major airlines on the TPE-HKG route during the period from July to September 2006. Only freighters are considered, and cargos transported by passenger aircraft are not included in the statistics. In Table 1, Eva Air accounts for the largest market share among all airlines on the route.

Table 2 shows time values and shipping amounts for cargos of various categories on the studied route. For temperature-control goods, this study further divides shippers into three groups. Shipper Group 10 consigns fresh cargos (15–25 °C); shipper Group 11 consigns chilled cargos (2–10 °C), and shipper Group 12 consigns frozen cargos (−18 °C to −25 °C).

This study assumes one season as the study period, which is also the timeframe in which airlines update new operation decisions in practice. The extra cost was comprised of, the cost of Cathay Pacific's PRIORITY service (Cathay Pacific Cargo, 2012) and the charges for priority checking at some of its major air cargo terminals. Currently, the charge for checking outbound goods with priority is 1 NTD/kg in Taiwan; for inbound goods, if the total weight of cargo does not exceed 3000 kg, the charge is 1000 NTD/Air waybill, and 2000 NTD/Air waybill for shipments exceed 3000 kg.

The proposed model was tested for reasonableness and feasibility before solving the optimal solution. To simplify the calculation, the study assumes the operation strategies and service parameters of competition airlines remain the same during the study period, the results show a steady state for the optimal solution exists after three iterations of demand-supply interactions. The results also show the object airline attracts 61,956,66 kg of cargos, which accounts for 41% of the whole market. The result is approximately equal to the actual market share of the object airline in 2006, 38.4%, which is shown in Table 1.

The current operation strategy of Eva Air (i.e., the object airline) is to offer alternatives including standard shipping and temperature control service. As regards the competitive airlines, China Airline provides standard shipping service with temperature control (China Airlines Cargo, 2012) and Cathay Pacific offers standard, express shipping and temperature control service (Cathay Pacific Cargo, 2012).

This study analyzes the operation cost, profit, and market share of Eva Air under different operation strategies through the model developed in Sections 2 and 3. In this example, the object airline takes four operation strategies into account, which are shown in Table 3. Strategies A and B offer only standard shipping without and with temperature control service, respectively. Strategy C combines standard and express shipping but no temperature control for either service. Finally, in Strategy D, the airline provides standard and express shipping with temperature control for both services.

Table 2
Shipping volumes on flights from Taipei to Hong Kong.
Source: Ministry of Transportation and Communications, R.O.C. (2006).

Category of cargos	Shipper group	Time value of cargo (USD/day/kg)	Amount (kg/season)
Chemical and rubber products	1	0.00015	12,390
	2	0.000219	16,933
	3	0.000255	23,433
Wood and paper products	4	0.000261	64,021
	5	0.00029	7898
	6	0.00058	8026
Processed food and textile products	7	0.00172	11,564
	8	0.00301	8218
	9	0.00645	8254
Agriculture goods (farm, forest, livestock and fishery products)	10	0.01209	27,593
	11	0.02418	62,008
	12	0.0372	33,203
Machinery	13	0.0395	626,300
	14	0.079	626,289
	15	0.1422	625,925
Electric machinery and apparatus	16	0.3	4,033,611
	17	0.65	5,787,222
	18	0.8	3,033,348

Table 3 shows the optimal operation strategy of the object airline. The results show that express service enables airlines to attract greater shipping volumes because there are large numbers of time-sensitive cargos on that route. Therefore, the airline should provide greater flight frequencies for those cargos. The market shares of all airlines with differentiated operation strategies are shown in Fig. 2. As Fig. 2 shows, if the object airline uses Strategy A, the market share of the object airline, which provides only standard shipping service without any priority or temperature control, is 40.4%, but Cathay Pacific, which provides high flight frequencies and priority service, attracts even greater shipping volume than the object airline.

When the object airline uses Strategy B instead of A, that is, the object airline offers standard shipping and temperature control service, the new temperature control service attracts some perishable goods and its market share increases 0.8%, which is shifted from Cathay Pacific. As a result, the object airline's operation profit also increases, as shown in Table 3. Similarly, compared with Strategies D with C, the temperature control service also increases the object airline's market share and profit when both strategies include express shipping. Therefore,

Table 3
Model results for object airline with various service combinations.

Strategy	Shipping service combination	Frequency (flights/week)		Shipping charge (USD/kg)				Total revenue (10^4 USD)	Operation cost (10^4 USD)	Total profit (10^4 USD)
		B747-400F	MD-11F	Normal	Fresh	Chilled	Frozen			
A	Standard shipping	8	1	0.7589	/	/	/	460.8	318.7	142
B	Standard shipping (with temperature control)	9	0	0.7589	1.4959	1.4389	1.5249	477.9	329.9	148
C	Standard shipping Express shipping	0 9	1 1	0.655 0.818	/ /	/ /	/ /	732	575.5	156.5
D	Standard shipping (with temperature control) Express shipping (with temperature control)	0 9	1 1	0.655 0.818	0.779 1.268	1.039 1.528	1.149 1.638	750.4	589.6	160.8

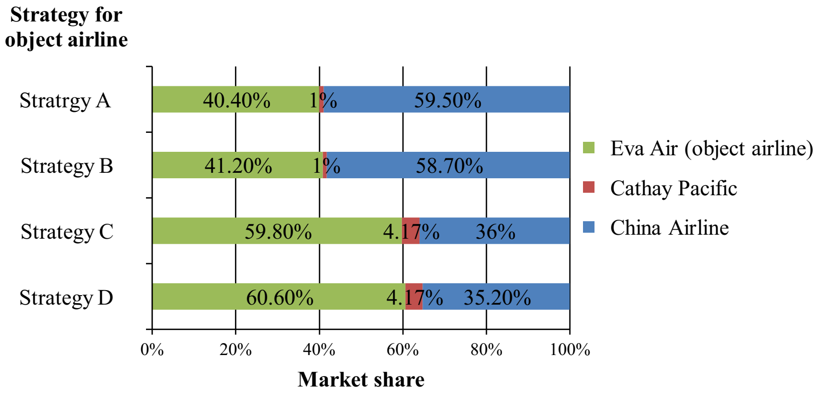

Fig. 2. Market shares of airlines with various shipping service combinations.

regardless of whether the airline provides express shipping, temperature control service can raise the market share and profit. Furthermore, comparing Strategy A with C, if the object airline provides standard and express shipping services simultaneously (i.e., Strategy C), more high time-value cargos are attracted by the greater flight frequency and priority handling of express service, and those increases are shifted mostly from Cathay Pacific. Finally, the results show that the object airline can gain the largest market share and make the most profit when offering alternatives, including standard shipping, express shipping, and temperature control services (i.e., Strategy D). This illustrates that it is feasible for the airline to provide differentiated strategies on the studied route. Compared with the current operation strategy of Eva Air (i.e., Strategy B), the results in Table 3 show that its market share increased by 19.4%, and total profit increased by 8.6% when the airline adopted the optimal strategy (Strategy D). On the other hand, compared with a situation where the object airline offers only standard shipping service (i.e., Strategy A), if the airline uses the optimal strategy in Table 3, its market share increases by 20.2% and total profit rise by 13.2%. The results show that simultaneously providing standard, express, and temperature control services can attract greater shipping volumes than other combinations.

Because the studied air route is a market composed mainly of high time-value goods, the major issue of sensitivity analysis is to determine the optimal strategy for a situation where the air cargo market is composed mainly of low time-value goods. For instance, consider a market composed of 70% chemical and rubber products, 10% processed food and textile products, 10% agriculture goods (farm, forest, livestock and fishery products), and 10% electric machinery and apparatus, (i.e., most cargos shipped on the route are low time-value). On this route, the average value of cargos per unit time is 0.051USD, and the percentage of cargos for which the value per unit time exceeds 0.051 USD is only 12%. In such a situation, if the airline offers express service, the shipping volume attracted by express service would be low, and the increased cost of providing express service might result in a deficit for the airline. Therefore, express service is not suitable for that type of market. The optimal planning result for the object airline for a low-time value cargo market is shown in Table 4, and market shares for all airlines providing different service combinations are shown in Fig. 3. Fig. 3 shows that the object airline can raise its market share 2% by offering temperature control service. If the airline only offers standard shipping service without temperature control service, it would lose the perishable cargo market. Besides, the object airline's increased shipping volumes are mostly shifted from Cathay Pacific; hence, the object airline's total profit raises 5.7%. Fig. 3 also shows that China Airline has the highest market share of low-value cargo among all airlines due to offering standard service with low charges and low flight frequencies.

5. Conclusions

This study constructs a shipping alternative choice model to analyze individual shipper's choice behavior considering different demand characteristics of cargos. This study also formulates an airline's cost function for providing different shipping services. Through the demand–supply interaction between shipping demand and service level, this study solves the optimal aircraft, flight frequencies, and charges for different shipping and temperature control services by maximizing the object airline's profit in the competitive air cargo market.

Table 4
Model results for object airline for a low-value cargo market with various service combinations.

Strategy	Shipping service combination	Frequency (flights/week)		Shipping charge (USD/kg)				Total revenue (10^4 USD)	Operation cost (10^4 USD)	Total profit (10^4 USD)
		B747-400F	MD-11F	Normal	Fresh	Chilled	Frozen			
A	Standard shipping	5	0	0.7659	/	/	/	376.5	225	151.4
B	Standard shipping (with temperature control)	5	0	0.7659	1.0969	1.3959	1.5069	409.4	249.3	160.1

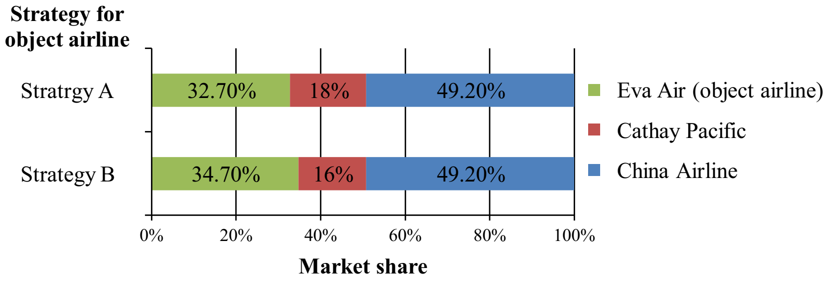

Fig. 3. Market shares of airlines for a low-value cargo market with various service combinations.

The results show that an airline should use smaller aircraft and offer greater frequency of flights for express service when shipping volume is low. Thus, not only airline operation costs but also shippers' inventory costs can be reduced by increasing flight frequency. The results also suggest that an airline should provide greater flight frequencies for high-value and time-sensitive cargos because shippers of such goods prefer efficient delivery. On the other hand, in the cargo market with mainly low time-value goods, airlines should not provide express shipping service because the shipping volume attracted by express service would be small, which does not justify the extra service cost. The findings imply that the higher the proportion of high time-value cargos to total shipping cargos, the larger the niche for airlines to provide express service, and the more the airline can charge.

For perishable goods that need to be stored in a low temperature environment to avoid quality decay, shippers of frozen (−18 °C to −25 °C) goods can save much more in decay costs than shippers of fresh (15–25 °C) or chilled (2–10 °C) goods if temperature control service is provided. The findings suggest that the lower the temperature environment in which the cargos need to be stored, the higher the shipping price the airline can charge. The results of different air cargo markets show that, no matter how great the shipping demand for perishable goods, temperature control service always belongs in the optimal shipping service combinations, which conforms to the airline's current operation in practice. For the route from Taipei to Hong Kong, which is a market comprised mainly of cargos of electrical apparatus, this study suggests that Eva Air provide differentiated services composed of standard shipping, express shipping, and temperature control services instead of its current service strategy. In sum, the airline should analyze the market structures of different routes and set service parameters based on cargo characteristics. In that way, the airline could enhance its market share in the industry.

Few studies have constructed mathematical models on issues investigated in this study. The mathematical model constructed herein supports the idea that airlines should design service products based on the shipping volume of specific routes with demand-supply interaction. The results of this study can be referred to by airlines when planning optimal shipping strategies for different cargo markets. The results of this paper not only verify that express cargo service is practicable in the high-value and time-sensitive cargo market, but also provides a decision-support tool for airlines in response to different market structures based on cargo time value and temperature. The decisions include service combinations, flight frequencies, shipping charges for different services, and estimates of cargo demand and profit.

This study can be extended in several ways. First, this study focuses on only a single route rather than all flights the object airline operates. Therefore, common costs shared by all flights cannot be accurately calculated. Future studies can extend the model by considering all of the routes the airline operates to make the model suitable for practicable situations. Second, except for freighters, airlines also use passenger aircraft to transport belly cargos; thus, future studies can add those effects into the model. Third, this study assumes that airlines have enough aircraft of all types for the frequency planning results. However, in practice, airlines need to consider the restrictions of the fleet, especially whether planned frequencies to satisfy all shipping demands exceed fleet capacity. Future studies can add the fleet constraints to conform to airline operations in practice. Finally, this study focuses on airline strategy planning and aims to maximize an airline's profit in response to different air cargo market structures. However, in practice, shippers may consider the reliability and risk of choosing a shipping service because air transportation is influenced by weather, import procedures, and unexpected events. Although shippers and carriers usually sign a claim contract for cargo damage and delivery delay, the damage and/or delay still result in losses for the shipper. Therefore, the reliability, risks, and related costs of shipping services should be considered. Future studies may improve the model by adding costs linked to reliability and risk.

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