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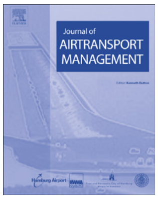

# Effects of cargo types and load efficiency on airline cargo revenues

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ABSTRACT

Numerous factors affect air cargo revenue management. Air cargo companies base their cargo charges on whichever is the greater of gross weight or volumetric weight. We developed a cargo consolidation model based on air cargo characteristics, and investigated the effect of cargo density, the Density Ratio of Heavy cargo to Light cargo (DRHL), and the percentage of small cargo on the chargeable weights and revenues of airlines. The empirical results show that a higher DRHL indicates greater chargeable weight, and that as the DRHL climbs to a certain level, the extent of chargeable cargo weights tends to stabilize gradually. The closer the cargo density approaches the most suitable loading density for a flight, the greater the chargeable weight is. A higher proportion of small cargo loaded on an aircraft means higher airline revenue. Our results can effectively combine types of air cargo to increase loading rates and revenues for airlines.

## 1. Introduction

In the past decade, as global trading has matured, international air cargo transport has experienced tremendous growth under the closely linked global supply chain. Over the next two decades air cargo is expected to increase at a rate of 4.5%–5.0% per year (Airbus, 2014; Boeing, 2014). Air cargo industry will continue to flourish in the wake of air transport liberalization (Wang and Heinonen, 2015), prospective long-haul low-cost carriers (Poret et al., 2015), and the implementation of the open skies agreement (Alves and Forte, 2015).

Airline companies are the main operators of air cargo transport responsible for airport-to-airport services. The participants of air cargo include shippers, air freight forwarders, customs brokers, cargo terminals, ground handling services. After customs clearance procedures, the cargo is packed and placed in a container and loaded onto the aircraft. Most airlines provide both passenger and cargo transport and outsource part of their cargo operations to airfreight forwarders. Consequently, international air cargo, an operation-intensive industry, involves complex decision-making procedures and numerous players. How airline companies can effectively combine types of air cargo to increase loading rates and revenues has become an important issue for operations management.

Unlike the fixed and known capacity of passenger seats, cargo space has greater uncertainty in terms of allocation and demand (Kasilingam, 1996; Morrell, 2011). Charges for airfreight are also complex and based on the gross weight or volume of the cargo, with the greater of the two as the chargeable unit. According to the IATA's list of airfreight rates, the greater the chargeable weight per shipment, the lower the unit price. Airfreight carriers consider both weight and volume when calculating their air cargo charges; thus, it is important to consider the relationship between the two when selling cargo space.

An aircraft loaded with excessively heavy cargo results in unused space because the aircraft has reached its maximum load, despite the cargo space not being fully used. In contrast, an aircraft carrying too much light cargo leads to wasted weight capacity because the total cargo weight is less than the aircraft's maximum load but its cargo space has reached full capacity. Therefore, accepting balanced quantities of heavy and light cargo ensures greater chargeable weights and increases revenues. As consignment weights increase, airline companies offer more favorable rates. This means that total revenues fluctuate depending on the percentage of large or small loads that aircrafts carry when the demand-supply-equilibrium game and the willingness to pay.

In summary, in terms of airfreight rates, it is necessary to

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consider multiple factors and limits because air cargo handling and freight charging are complex. Therefore, we created several mathematical models concerning flight charges, ULD weight limits, cargo weight, and balance to examine the effect of air cargo density, the Density Ratio of Heavy cargo to Light cargo (DRHL), and the percentage of small cargo on chargeable weights and revenues. We also provide operations management references for airline companies. The remainder of this paper is organized as follows: Section 2 presents a review of the relevant literature, Section 3 provides the model formulation details, while Section 4 presents its application. Finally, Section 5 offers concluding remarks and suggestions for future research.

## 2. Literature review

We mainly examined the characteristics of air cargo loading and factors affecting air cargo revenues. Because of aircraft restrictions, passenger planes can only carry cargo in the belly. In this case, fuel, the number of passengers, and quantity of baggage determine payloads and aircraft cargo space. The ULD used varies according to aircraft types, and different ULDs have specific weight and volume limits. Airline companies determine the number of pallets and containers allowed based on booking information from forwarders and cargo types, and the suitable types of ULD for aircrafts.

Over the past years, more attention has been paid to the problem that precedes airline container loading problem with pickup and delivery by considering how to optimize freight loading within ULDs (http://www.sciencedirect.com/science/article/pii/S0377221715001289Li et al., 2009, http://www.sciencedirect.com/science/article/pii/S0377221715001289Tang, 2011, and http://www.sciencedirect.com/science/article/pii/S0377221715001289Wu, 2010) independently of aircrafts. Vancroonenburg et al. (2014) attempted to determine how to select the ULDs or items to be loaded in an aircraft or a fleet of aircraft, whereas others assumed that all ULDs must be loaded in the aircraft.

For aircraft structural safety, weight limits exist for every position and area inside the aircraft cargo holds (see operation manuals for different aircraft types). Forwarders can also choose between more containers or more pallets depending on whether the plane carries more cargo in small cardboard boxes, irregular voluminous light cargo, or larger cargo. Chan et al. (2006) presented a two-phase intelligent decision support system for the air cargo loading problem. They developed a new approach for the air cargo 3D loading plan on differently shaped and sized pallets.

Previous studies of airline cargo management has focused mainly on cost analysis (Chao and Hsu, 2014; Lakew, 2014; Mayer and Scholz, 2012). Yan et al. (2008) developed a stochastic demand cargo container-loading plan model to minimize total operating cost, subject to the related operating constraints. The results show the model and the solution method to be useful for air express carriers. For the air cargo revenue management problem, Huang and Chang (2010) developed a solution algorithm based on approximating the expected revenue function in the dynamic programming (DP) model while accounting for the stochastic volume and shipment weight. Han et al. (2010) considered booking acceptance and rejection options for airline companies. They assumed that each booking request is endowed with a random weight and volume, and proposed a Markovian model for calculating and deciding whether to accept booking requests as a reference for airline companies in allocating aircraft cargo capacities.

## 3. Model formulation

Airfreight charging characteristics necessitate considering both weight and volume. Therefore, chargeable weight is greater when the aircraft cargo has a higher ratio of low-volume heavy cargo to high-volume light cargo. This section provides an airfreight charging model, a description of a mathematical model involving the factors affecting air cargo revenues, and limits of ULD loading onto the aircraft.

### 3.1. Airfreight charging model

Charges for airfreight account for both cargo weight and volume, and the greater of the two is the chargeable weight. The conversion from cargo volume to volumetric weight, according to IATA criteria, is that the volume (in cubic centimeters) divided by 6000 (5000 for express carriers). According to the IATA list of airfreight rates, airline companies charge different unit prices based on chargeable weights by cargo types. As chargeable weights increase, airline companies offer more favorable rates. Table 1 lists the air cargo delivery rates from Taipei (TPE) to Dallas Fort Worth International Airport (DFW) in the United States in 2013. If the chargeable weight is less than 44 kg, the unit price is US$12.66/kg. However, the minimum charge is US$70, which means that the freight remains US$70 for all chargeable weights less than 5 kg. If the chargeable weight is between 35 and 45 kg, the charges are calculated using US$438.3(9.74*45). Fig. 1 shows a summary of the relationships between chargeable-weight class intervals and total prices in 2013. In this study, small cargo refers to cargo whose freight rate is not the lowest. Take the TPE-DFW delivery route for example, small cargo on this route refers to cargo whose chargeable weight is less than 1000 kg (i.e., whose freight rate is higher than US$5.44).

According to the pricing characteristics, let $\sigma^{ft}$ represent airline revenue from the flight of an $f$-type aircraft on route $t$. $\sigma^{ft}$ can be formulated as

$$\sigma^{ft} = \sum_{b} Max\left\{\sum_{i} Min\left(B_{bi}^{ft}\cdot \widehat{w}_{b}^{ft}\cdot P_{i}^{t}\left(\widehat{w}_{b}^{ft}\right),\ W_{i+1}\cdot P_{i+1}^{t}\right),\ M^{t}\right\} \forall f,t \tag{1}$$

$$\widehat{w}_{b}^{ft} = Max\left\{W_{b}^{ft}, \frac{V_{b}^{ft}}{\gamma}\right\} \quad \forall f,t,b \tag{2}$$

$$B_{bi}^{ft} = \begin{cases} 1 & if \quad \widehat{w}_{b}^{ft} \in (W_i, W_{i+1}] \\ 0 & otherwise \end{cases} \quad \forall f,t,b, \tag{3}$$

where $\widehat{w}_{b}^{ft}$, $P_{i}^{t}(\widehat{w}_{b}^{ft})$, $W_{b}^{ft}$, and $V_{b}^{ft}$ are the chargeable weight, unit price, gross weight, and volume on the master airway bill $b$ of an $f$-type aircraft on route $t$, respectively; $\gamma$ represents the IATA criteria for the volume to volumetric weight conversion for air cargo. Depending on whether the volume is in cubic centimeters or cubic feet, the constant is 6000 (5000 for express carriers) or 0.2119[1] (0.1765 for express carriers). The chargeable weight of a master airway bill can be calculated using Equation (2). $W_i$ are the weight boundaries of rate class interval $i$, and $M^t$ is the minimum charge for route $t$. The symbol definitions in this study are shown at Appendix A.

### 3.1.1. How the DRHL affects chargeable weights

Airline companies base their charges on weight for heavy cargo and volume for light cargo. The higher the DRHL on a flight, the

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[1] 1 foot = 12 × 2.54 cm; 6000 cubic centimeters = 0.2119 ($6000 \div 12^3 \div 2.54^3$) cubic feet.

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**Table 1**
Rate-class intervals for the TPE-DFW delivery route.

| C.W. (kg) | | ~44 | 45–99 | 100–299 | 300–499 | 500–999 | 1000~ |
|---|---|---|---|---|---|---|---|
| Rate (US$) | 70(M)* | 12.66 | 9.74 | 9.07 | 7.16 | 6.27 | 5.44 |
| Weight class (kg) | 6 | 35 | 94 | 237 | 438 | 869 | .. |

Note: C.W. = Chargeable weight; * denote minimum charge.
Source: International Air Transport Association, IATA (2013).

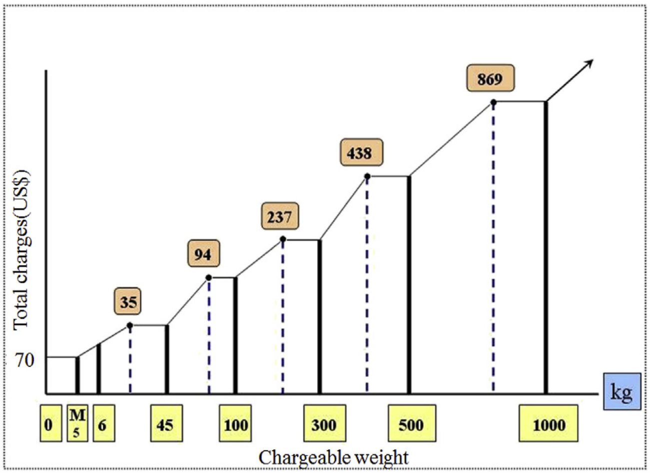

**Fig. 1.** Relationships between chargeable weights and total charges.

greater the chargeable weight. The value obtained by dividing the density of heavy cargo (of which the chargeable weight is gross weight) by that of light cargo (of which the chargeable weight is volumetric weight) on the same flight is called the DRHL. A higher ratio indicates a greater density difference between heavy and light cargo. In contrast, a lower ratio means that aircraft cargo is mostly neutral and similarly dense. Let $R^{ft}$ represent the DRHL for an $f$-type aircraft on route $t$. $R^{ft}$ can be formulated as

$$R^{ft} = \frac{\sum\limits_{b} \left( I_b^{ft} \cdot \frac{W_b^{ft}}{V_b^{ft}} \cdot \frac{V_b^{ft}}{\sum\limits_{b} I_b^{ft} \cdot V_b^{ft}} \right)}{\sum\limits_{b} \left[ \left(1 - I_b^{ft}\right) \cdot \frac{W_b^{ft}}{V_b^{ft}} \cdot \frac{V_b^{ft}}{\sum\limits_{b} \left(1 - I_b^{ft}\right) \cdot V_b^{ft}} \right]} \tag{4}$$

$$I_b^{ft} = \begin{cases} 1 \quad if \quad \frac{W_b^{ft}}{V_b^{ft}} \geq 4.72 \\ 0 \quad if \quad \frac{W_b^{ft}}{V_b^{ft}} < 4.72 \end{cases} \tag{5}$$

where $I_b^{ft}$ is an indicator variable denoting that the cargo of the master airway bill $b$ handled by an $f$-type aircraft on route $t$ is heavy cargo or light cargo. Cargo is defined either as heavy cargo, $I_b^{ft} = 1$, or light cargo, $I_b^{ft} = 0$, depending on whether its density is higher or lower than 4.72 (1/0.2119) as shown in Equation (5).

### 3.1.2. *How cargo density affects aircraft load efficiency*

Because all aircrafts have fixed-limited loading weights and space, higher cargo density loaded onto an aircraft means that the aircraft carries heavier cargo and wastes aircraft space because of remaining unused space, although the aircraft has reached its maximum loadable weight. In contrast, a lower cargo density loaded onto an aircraft means that the aircraft carries lighter cargo and wastes aircraft weight capacity because of remaining unused loading weight, although the aircraft's loadable space has been used. Therefore, the density of cargo loaded onto aircrafts has an effect on load efficiency and chargeable weight.

The optimal combination of cargo types refers to the full use of an aircraft's loadable weight and volume. Under the condition that the aircraft type and flight route are known, it is possible to calculate its optimal loading density. The optimal loading density of an $f$-type aircraft on route $t$ is the aircraft's loadable weight divided by its loadable volume, as shown in Equation (6).

$$D^{ft} = \frac{w^{ft}}{v^{f}} \tag{6}$$

where $w^{ft}$ is the maximum payload of an $f$-type aircraft on route $t$, and $v^{f}$ is the maximum loadable volume of an $f$-type aircraft. Take a B747–400F all-cargo aircraft as an example, and assume that its maximum loading volume is 21,000 cu ft. If the maximum payload weight on a flight is 110,000 kg, then the optimal density for the flight should be 5.238 kg/cu ft.

Different aircraft types have different loading weight and volume limits. Airline companies should always calculate the average density of consignments to use the aircrafts' loadable weights and volumes. Whether the average density of consignments is higher or lower than the optimal aircraft loading density indicates a bias toward either heavy or light cargo and the necessity of receiving either lower-density light cargo or higher-density heavy cargo in the future. Divide the cargo weight on each master airway bill of one cargo flight by the cargo volume, and then multiply by the percentage of the cargo on this bill in the entire cargo on this flight. The sum of the results for all the master airway bills is the average cargo density on this flight. If $\overline{D}^{ft}$ represents the average density of cargo loading on an $f$-type aircraft for route t, $\overline{D}^{ft}$ can be formulated as

$$\overline{D}^{ft} = \sum_{b} \frac{W_b^{ft}}{V_b^{ft}} \cdot \frac{V_b^{ft}}{\sum\limits_{b} V_b^{ft}} \tag{7}$$

With Equation (7), it is always possible to calculate the average density of currently received cargo per flight, which can then be compared with the optimal loading density in that flight based on Equation (6). If the average density of currently received cargo is higher, light cargo with lower density should be received in the future. On the contrary, heavy cargo with higher density should be received if the average density of currently received cargo is lower.

### 3.1.3. *How small cargo percentage affects air cargo revenues*

Airline companies implement rate differentiation and charge higher unit prices for small cargo; thus, the percentage of small cargo loaded onto aircrafts also affects revenues from these flights when the demand-supply-equilibrium game and the willingness to pay. The list of differential rates indicates that a higher percentage

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of small cargo on a flight means more cargo for which high-unit prices are charged and higher airline revenues. The percentage of small cargo on an *f*-type aircraft for route *t*, $s^{ft}$, is the sum obtained by adding the percentage of small cargo $s_b^{ft}$ under each master airway bill *b* on an *f*-type aircraft for route *t*. $s^{ft}$ can be formulated as

$$s^{ft} = \sum_b s_b^{ft} \tag{8}$$

$$s_b^{ft} = \frac{\left(\left(\frac{P_i^t\left(\widehat{w}_b^{ft}\right)}{P_I^t}\right) - 1\right)}{\left(\left(\frac{P_o^t}{P_I^t}\right) - 1\right)} \times \frac{\widehat{w}_b^{ft}}{\sum_b \widehat{w}_b^{ft}} \quad , \quad i = 0, 1, ..., I-1 \tag{9}$$

where $P_0^t$ and $P_I^t$ are the unit prices (US$/kg) in the maximum and minimum rate class intervals for route *t*, respectively. The percentage of small cargo on each flight indicates the following relationship between the percentage and the revenue, which can be formulated as

$$\sigma^{ft} = \sum_b \widehat{w}_b^{ft} \times \left(P_I^t + s^{ft}\left(P_o^t - P_I^t\right)\right) \tag{10}$$

The equation indicates that the average unit price $(P_I^t + s^{ft}(P_o^t - P_I^t))$ is the unit price in the minimum rate class interval $P_I^t$ when the percentage of small cargo is 0, and the unit price in the maximum rate class interval is $P_0^t$ when the percentage is 1. In the other cases, the unit price is between $P_I^t$ and $P_0^t$, and increases as the percentage of small cargo becomes larger.

### 3.2. Limits of ULD loading

Because ULD types vary with aircraft types, in order to determine the number of pallets and containers to be used and their best combinations, airline cargo staff combine the ULDs based on aircraft types, according to booking data, cargo types, and loading manuals provided by aircraft manufacturers. The total cargo weight and volume that an aircraft carries should not exceed the total loadable weight and volume of all ULDs, formulated as

$$\sum_k \sum_b W_b^{ft} \cdot J_{bk}^{ft} \le \sum_k W_k \cdot n_k^{ft} \tag{11}$$

$$\sum_k \sum_b V_b^{ft} \cdot J_{bk}^{ft} \le \sum_k V_k \cdot n_k^{ft} \tag{12}$$

$$\sum_k J_{bk}^{ft} = 1 \quad , \quad \forall f, \forall t \tag{13}$$

$$\sum_k E_k \cdot n_k^{ft} \le E^f \tag{14}$$

where $W_k$ and $V_k$ are the loadable weight and volume of a *k*-type ULD, respectively; $n_k^{ft}$ is the number of *k*-type ULDs that can be loaded onto the flight operated by an *f*-type aircraft on route *t*; $J_{bk}^{ft}$ is the indicator variable indicating whether the cargo of the master airway bill *b* handled by an *f*-type aircraft on route *t* is loaded onto a *k*-type ULD; if yes, then $J_{dbk}^{ft} = 1$; otherwise, $J_{dbk}^{ft} = 0$. $E_k$ and $E^f$ are the bottom areas of a *k*-type ULD and the total ULD area that is loadable onto an *f* type aircraft, respectively. Equations (11) and (12) ensure that the total weight and volume of the entire cargo are smaller or equal to the loadable weight and volume of a ULD on an *f*-type aircraft for route *t*. Equation (13) ensures that the cargo under each master airway bill *b* is loaded onto only one type of ULD. Equation (14) limits the number of types of ULDs used on an *f*-type aircraft for route *t*, such that it does not exceed the maximum allowable number.

Airline companies can plan the DRHL, the cargo density, and the percentage of small cargo for each flight according to aircraft types and in compliance with ULD loading limits to increase total revenues from cargo flights.

## 4. Model application

We used an example as the actual operational data of a Boeing 747–400F all-cargo aircraft flying from Taipei to Dallas (TPE-DFW), operated by a Taiwanese Airline Company A to verify the DRHL, cargo density, and the percentage of small cargo on the revenue from this flight.

### 4.1. How the DRHL affects chargeable weights

To examine how different cargo-type combinations affect flight-chargeable weights, we used the TPE-DFW flight on March 15, 2014 to provide an example. There are total 133 batches of cargo. The gross weight and volume per patch is provided in Appendix B and the gross weight and volume of all the cargo amount to 219,470 kg and 42,786 cu ft. We used the maximum payload of 110,000 kg and the maximum volume of 21,000 cu ft of the B747–400F all-cargo aircraft flying the TPE-DFW route. Assuming that both volume and weight uses were nearly 100%, we obtained various density ratios of heavy cargo to light cargo by using part of the 133 batches of cargo to build Scenarios 1–11 and to calculate chargeable weights in these scenarios (Table 2). Fig. 2 shows their relationship. The results indicate that a higher DRHL loaded on the aircraft leads to a greater chargeable weight. This is because charges are based on the gross weight for heavy cargo and the volume for light cargo, and both cargo types are mutually offset in weight and volume. The chargeable weight increases the DRHL when using both volume and weight. Scenarios 10–11 also show that the extent to which chargeable weights of cargo increase tends to stabilize gradually when DRHLs reach a certain level. Chargeable weight growth is 17.1% from Scenario 1 as the benchmark until Scenario 11. For example, Scenario 11 has in total 103 batches of cargo loaded as shown in numbers in bold in Appendix B. This means that airline companies may increase their revenues by accepting more heavy and light cargo, thereby increasing chargeable weights.

### 4.2. How cargo density affects chargeable weights

To investigate how cargo-type combinations affect flight chargeable weights, we used flights operated by a B747–400F all-cargo aircraft for the TPE-DFW route and three DRHL, 3.0, 2.5, and 2.0, to examine how chargeable weights change with cargo density, from the lowest in Scenario *A* to the highest in Scenario *H*. The results in Table 3 show that chargeable weights increase together for three DRHLs, and reach their maximum when the loading density is 5.2 kg/cu ft (Scenario *F*). Chargeable weights start to decline as the density increases when it exceeds the foregoing value. This is because the cargo density loaded onto an aircraft that is lower than the optimal density means that the aircraft carries more light cargo, resulting in wasted weight capacity because of remaining unused loading weight, although its loadable space has been used. In contrast, a cargo density loaded onto an aircraft higher than the optimal density means that the aircraft carries more heavy cargo, resulting in wasted space because of remaining

**Table 2**
How different combinations of cargo types affect chargeable weights.

| Scenario | G. W.$^{a}$ (1) | V.W.$^{a}$ (2) | G. W.$^{b}$ (3) | V.W.$^{b}$ (4) | DRHL[a] [(1)÷(2)]÷[(3)÷(4)] | C.W. (1)+(4) | Growth |
|---|---|---|---|---|---|---|---|
| 1 | 79,047 | 64,440 | 30,732 | 34,524 | 1.38 | 113,571 | – |
| 2 | 64,718 | 46,958 | 45,282 | 52,082 | 1.59 | 116,800 | 2.8% |
| 3 | 70,782 | 50,199 | 38,738 | 48,518 | 1.77 | 119,300 | 5.0% |
| 4 | 69,498 | 46,580 | 40,267 | 52,510 | 1.95 | 122,008 | 7.4% |
| 5 | 72,855 | 37,106 | 53,076 | 51,058 | 2.09 | 123,913 | 9.1% |
| 6 | 65,025 | 38,645 | 44,954 | 60,446 | 2.26 | 125,471 | 10.5% |
| 7 | 63,335 | 35,671 | 49,520 | 63,168 | 2.42 | 126,503 | 11.4% |
| 8 | 75,700 | 45,650 | 33,932 | 53,049 | 2.59 | 128,749 | 13.4% |
| 9 | 73,972 | 41,976 | 36,026 | 56,989 | 2.79 | 130,961 | 15.3% |
| 10 | 67,092 | 34,130 | 42,697 | 64,947 | 2.99 | 132,039 | 16.3% |
| 11 | 66,862 | 32,848 | 42,769 | 66,167 | 3.15 | 133,029 | 17.1% |

Note: G.W. = Gross weight; V.W. = Volumetric weight; C.W. = Chargeable weight; unit: kg.
a and b denote the heavy cargo and the light cargo, respectively.
[a] DRHL denotes the density ratio of the heavy cargo to the light cargo.

unused space, although the aircraft has reached its maximum loadable weight.

Fig. 3 shows a comparison of chargeable weights in different loading densities for three DRHLs. The figure shows greater chargeable weight for higher ratios when the cargo densities are similar. The chargeable weight is greater for the DRHL at 3.0, compared for the DRHLs at 2.5 and 2.0. However, flights with higher DRHLs have less chargeable weight than those with lower DRHLs if their cargo combinations fail to reach the optimal cargo density (e.g., chargeable weights in Scenarios *A*-*E* and *H*, which have a DRHL of 3.0, are all less than in Scenario *F*, which has a DRHL of 2.5). This means that airline companies should consider both the DRHL and the optimal loading density during cargo canvassing to maximize chargeable weights. A good example is Scenario *F* with a DRHL of 3.0. However, the actual rates charged by airlines may vary according to market situations and may thus differ from the tariffs published by IATA. It is suggested that further research may further compare changes associated with different market rates.

Because of fixed available cargo space, the cargo volume that aircrafts with different ranges can carry remains the same. However, because longer ranges mean more fuel, all aircraft types have maximum takeoff weight limits. Apart from a force majeure (e.g., weather or runway length), aircraft maximum payload weights decline along a slope as flight distances increase (Fig. 4). Short ranges are suitable for denser cargo (e.g., Point A in Fig. 4) because

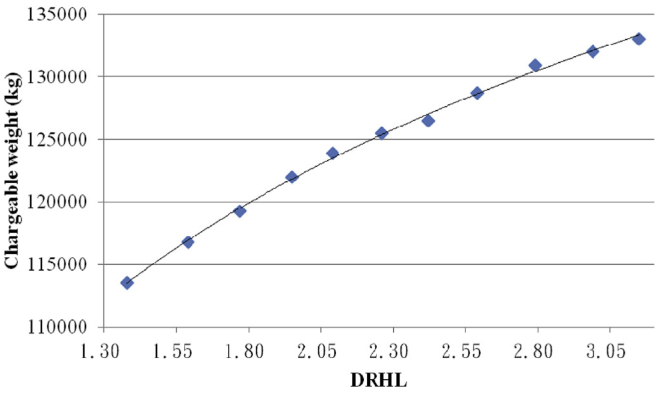

**Fig. 2.** Relationship between DRHL and chargeable weights.

**Table 3**
Relationship between cargo density with different DRHLs and chargeable weights.

| Scenario | DRHL[a] = 3.0 | | DRHL[a] = 2.5 | | DRHL[a] = 2.0 | |
|---|---|---|---|---|---|---|
| | Density | C.W. | Density | C.W. | Density | C.W. |
| *A* | 3.9 | 106,945 | 3.9 | 106,077 | 3.9 | 105,349 |
| *B* | 4.1 | 110,956 | 4.1 | 109,421 | 4.1 | 108,757 |
| *C* | 4.4 | 115,985 | 4.4 | 114,192 | 4.4 | 112,305 |
| *D* | 4.7 | 120,216 | 4.7 | 117,176 | 4.7 | 114,650 |
| *E* | 5.0 | 128,238 | 5.0 | 122,018 | 5.0 | 118,777 |
| *F* | 5.2 | 131,780 | 5.2 | 128,548 | 5.2 | 123,555 |
| *G* | 5.5 | 129,822 | 5.5 | 125,162 | 5.5 | 121,495 |
| *H* | 5.8 | 126,861 | 5.8 | 122,485 | 5.8 | 118,533 |

Note: C.W. = Chargeable weight; unit: kg.
[a] DRHL denotes the density ratio of the heavy cargo to the light cargo.

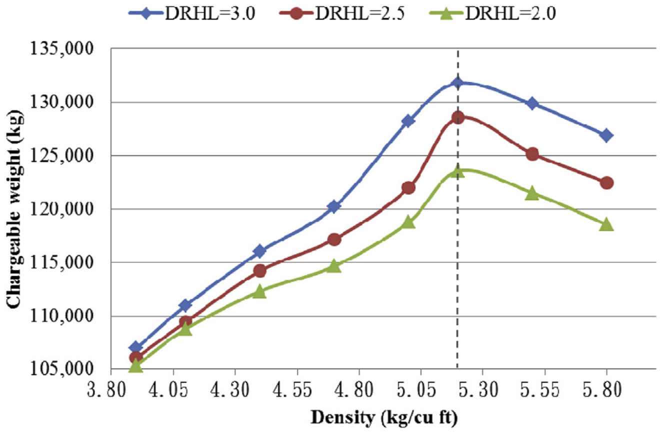

**Fig. 3.** Relationship between cargo density with different DRHLs and chargeable weights.

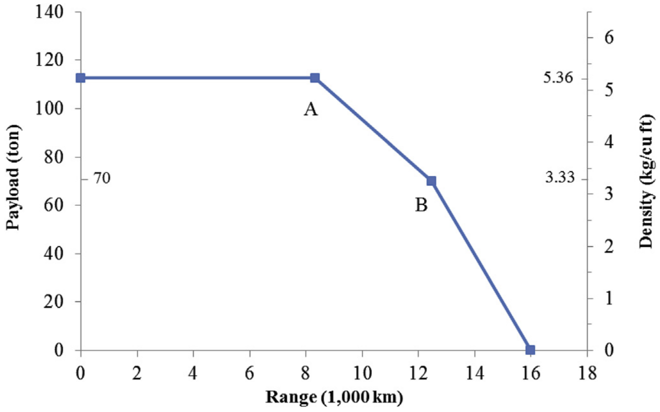

**Fig. 4.** B747–400F all-cargo aircraft payload range and optimal density.

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they allow greater payload weight and full use of loadable space and weight for cargo carried. In contrast, long-range flights are suitable for less dense cargo (e.g., Point B in Fig. 4) because they have less payload weight and the same cargo space as their long-range counterparts. Equation (6) calculates the optimal loading densities for different flight ranges. For a B747–400 all-cargo aircraft, optimal loading densities decrease as ranges increase, as shown in Fig. 4. Airline companies can determine the percentage of cargo with different densities by referring to optimal loading densities to increase space and weight use and total revenues from flights.

### 4.3. How percentages of small cargo affect revenues

Table 1 in Section 3 shows that cargo unit prices are higher or lower with less or more consignment chargeable weights. To investigate how small-cargo percentages on flights affect revenue, we used all the cargo listed in Appendix B to calculate the small-cargo percentage on each of these flights by using Eqs. (8) and (9), and sorted the resulting percentages in ascending order. Table 4 shows that revenues increase with the small-cargo percentage. The revenue is US$723,787 when the small-cargo percentage is 0, and increases to US$758,597 when the percentage rises to 4.01%. The growth of revenue is 4.81%. Fig. 5 shows the relationship between small-cargo percentages and revenues. Revenues increase when more small cargo is charged for higher unit prices.

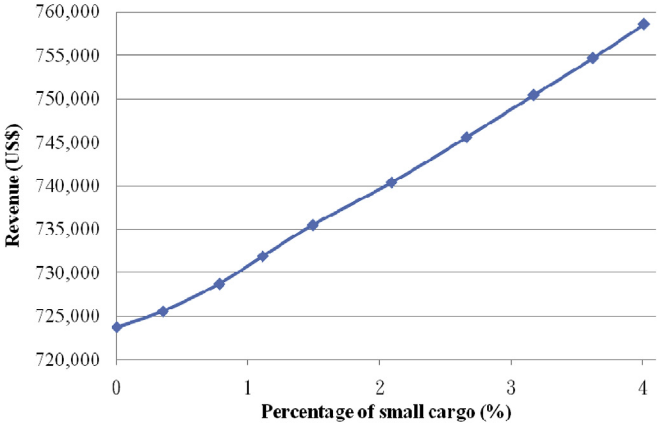

**Fig. 5.** Relationship between small-cargo percentages and revenues.

## 5. Conclusion

This study has validated the factors affecting air cargo revenues, including the DRHL, cargo density, and the percentage of small cargo. Further, we empirically verified our calculations based on the actual operations of a B747–400F all-cargo aircraft operated by a Taiwan airline company. We summarize our conclusion as follows:

1. Under the condition of fully using loadable space and flight payloads, chargeable weights increase with DRHL, and the extent to which these weights increase tends to stabilize gradually when the DRHL rises to a certain level. This indicates that airline companies can accept more cargo combinations of denser heavy cargo and less dense light cargo for the same flight to increase chargeable weights and revenues.
2. Chargeable weights increase when the average cargo densities loaded onto flights approach optimal loading densities for these flights. Therefore, airline companies should control average cargo densities, and ensure that they are close to optimal for flights, while increasing the DRHL by accepting both cargo types to increase space and weight use and to maximize revenues.
3. Because of fixed cargo space, short-range and long-range flights are more suitable for carrying highly dense and less dense cargo, respectively, because short-range flights allow larger payloads, whereas long-range flights allow smaller payloads. Airline companies can determine cargo percentages with different densities by referring to optimal loading densities to increase total revenues from flights.
4. As consignment weights increase, airline companies offer more favorable rates when the demand-supply-equilibrium game and the willingness to pay. This means that total revenues fluctuate depending on the percentages of large or small cargo that aircrafts carry.

**Table 4**
Comparison between small-cargo percentages and revenues.

| No | Percentage* | C.W.(kg) | Revenue(US$) | Growth |
|---|---|---|---|---|
| 1 | 0.00% | 133,029 | 723,787 | – |
| 2 | 0.35% | 133,029 | 725,595 | 0.25% |
| 3 | 0.78% | 133,029 | 728,754 | 0.69% |
| 4 | 1.11% | 133,029 | 731,923 | 1.12% |
| 5 | 1.49% | 133,029 | 735,510 | 1.62% |
| 6 | 2.09% | 133,029 | 740,395 | 2.29% |
| 7 | 2.66% | 133,029 | 745,590 | 3.01% |
| 8 | 3.17% | 133,029 | 750,439 | 3.68% |
| 9 | 3.62% | 133,029 | 754,689 | 4.27% |
| 10 | 4.01% | 133,029 | 758,597 | 4.81% |

Note: *percentage of small cargo; C.W. = Chargeable weight.

We examined factors affecting revenue management and conducted modeling based on the management of air cargo revenues. Although the results of the empirical analysis conducted mostly match practical situations, we offer the following suggestions as references for future research:

1. We mainly investigated how cargo types affect the chargeable weights and revenues of airline companies and focused less on how to select ULDs suitable for different cargo types. Future research could examine how ULD loading efficiency and cargo-type combinations affect air cargo revenues for more comprehensive research.
2. We created mathematical models and conducted an empirical verification based on air cargo practices. Subsequent researchers may integrate information systems and develop applications for airline companies to increase their revenues by determining optimal cargo combinations, increasing ULD loading efficiency, and maintaining weight and balance.
3. Airline companies make loading passenger baggage onto passenger or combo aircrafts their first priority. Consequently, loadable volumes and weights of flights vary according to flight ranges and passenger-load factors. Future research could examine the cargo-loading efficiency of passenger and combo aircrafts and their revenues.
4. Since the actual rates charged by airlines may vary according to market situations and may thus differ from the tariffs published by IATA. It is suggested that further research may compare the composition of freight and revenues of other carriers based on different market rates to further plan the DRHL, the cargo density, and the percentage of small cargo for each flight according to aircraft types and in compliance with ULD loading limits to increase total revenues from cargo flights.

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## Appendix A. Glossary of symbols

| | |
|---|---|
| $b$ | number of master airway bills |
| $D^{ft}$ | optimal density of the cargo handled by an *f*-type aircraft on route *t* |
| $\overline{D}^{ft}$ | average density of the loading cargo handled by an *f*-type aircraft on route *t* |
| $E_k$ | bottom area of a *k* type ULD |
| $E^f$ | loadable total area of ULD on an *f*-type aircraft |
| $f$ | type of aircraft |
| $I_b^{ft}$ | an indicator variable denoting whether the cargo of the master airway bill *b* handled by an *f*-type aircraft on route *t* is heavy cargo or light cargo |
| $i$ | rate class interval |
| $J_{bk}^{ft}$ | a variable indicating whether the cargo of the master airway bill *b* handled by an *f*-type aircraft on route *t* is loaded on a *k*-type ULD |
| $k$ | type of ULD |
| $M^t$ | minimum charge on route *t* |
| $n_k^{ft}$ | loadable number of a *k*-type ULDs handled by an *f*-type aircraft on route *t* |
| $P_I^t$ | unit price in the lowest rate class interval on route *t* |
| $P_0^t$ | unit price in the highest rate class interval on route *t* |
| $P_i^t$ | unit price in the rate class interval *i* on route *t* |
| $P_i^t(\widehat{w}_b^{ft})$ | unit price on the master airway bill *b* handled by an *f*-type aircraft on route *t* |
| $R^{ft}$ | DRHL handled by an *f*-type aircraft on route *t* |
| $s^{ft}$ | percentage of small cargo handled by an *f*-type aircraft on route *t* |
| $s_b^{ft}$ | percentage of small cargo on the master airway bill *b* handled by an *f*-type aircraft on route *t* |
| $t$ | route of a flight |
| $V_k$ | loadable volume of a *k*-type ULD |
| $V_b^{ft}$ | volume of the master airway bill *b* handled by an *f*-type aircraft on route *t* |
| $v^f$ | maximum loadable volume of an *f*-type aircraft |
| $W_i$ | weight boundaries of the rate class interval *i* |
| $W_k$ | loadable weight for a *k*-type ULD |
| $W_b^{ft}$ | weight of the master airway bill *b* handled by an *f*-type aircraft on route *t* |
| $w^{ft}$ | maximum payload of an *f*-type aircraft on route *t* |
| $\widehat{w}_b^{ft}$ | chargeable weight on the master airway bill *b* handled by an *f*-type aircraft on route *t* |
| $\sigma^{ft}$ | revenue from the flight handled by an *f*-type aircraft on route *t* |
| $\gamma$ | IATA criteria for volume to volumetric weight conversion for air cargo |

## Appendix B. The goods for the TPE-DFW delivery route

| No | Nature of goods | kg | cu ft | No | Nature of goods | kg | cu ft |
|---|---|---|---|---|---|---|---|
| 1* | Helmet | 29 | 16.6 | **68** | Vale control board | 135 | 22.5 |
| 2 | DIP Switches | 722 | 148.3 | **69** | Civil aircraft | 23 | 5.7 |
| 3 | Navigation autopilot device | 3084 | 961.7 | 70 | Fixed wireless | 8308 | 1094.8 |
| 4 | Arm hight sensing | 132 | 7.2 | **71** | Clothing knit | 613 | 138.5 |
| 5 | LCD monitor | 646 | 167.0 | 72 | NB computer | 1391 | 259.2 |
| 6 | Decorative chrome plastic plating | 4879 | 1297.7 | **73** | Switch assy tru | 180 | 43.4 |
| 7 | Printed circuit boards | 293 | 21.4 | **74** | New automotive parts | 14 | 1.8 |
| 8 | Mould components | 3439 | 95.3 | 75 | Didnanosine international | 1989 | 446.2 |
| 9 | Jack | 145 | 9.3 | **76** | NB computer | 158 | 36.7 |
| 10 | Test strip | 3084 | 647.5 | **77** | Car antenna | 570 | 88.3 |
| 11 | Handle piece mold | 272 | 3.5 | **78** | Connector harness | 592 | 88.2 |
| 12 | Mold base | 190 | 10.6 | **79** | Stabilizer bar | 4468 | 311.9 |
| 13 | Aircraft parts nozzle | 68 | 15.1 | **80** | Notebook | 155 | 27.5 |
| 14 | SNYC charger UBS | 24 | 24.3 | **81** | iphone 5S | 4230 | 509.8 |
| 15 | Shower enclosure | 87 | 21.2 | **82** | iphone 5S gold | 89 | 14.8 |
| 16 | Lowers | 112 | 71.4 | 83 | iphone 5S | 2913 | 363.6 |
| 17 | Bandage | 5177 | 1217.3 | **84** | iphone 5S | 178 | 29.7 |
| 18 | Cable | 1602 | 362.5 | **85** | Shoes | 2641 | 1020.3 |
| 19 | Machine parts | 3172 | 955.0 | **86** | Connector | 416 | 105.9 |
| 20 | Handset for TRA | 4180 | 882.9 | **87** | Computer peripheral | 430 | 119.5 |
| 21 | Footwear womens | 3323 | 706.3 | **88** | Blender cup | 629 | 130.7 |
| 22 | DC miniature MO | 110 | 14.1 | **89** | Buick 1992CC vehicle | 2349 | 785.9 |
| 23 | Hub TC pump | 506 | 41.5 | 90 | Notebook | 236 | 50.0 |
| 24 | Hub TC pump | 510 | 40.5 | **91** | Cargo net | 1887 | 162.2 |
| 25 | Shredder part | 2154 | 106.3 | **92** | NB computer | 677 | 150.1 |
| 26 | Injection mold | 3209 | 53.3 | **93** | Men S knit hoody | 47 | 35.3 |
| 27 | Hard disk drive | 712 | 109.5 | **94** | T45 victory track jacket | 142 | 36.7 |
| 28 | Nut | 611 | 21.0 | **95** | LMA flexible | 207 | 105.9 |
| 29 | Alluminium die cast part | 254 | 77.7 | **96** | 300560 | 1193 | 485.3 |
| 30 | Computer parts chassis | 174 | 105.9 | **97** | Cable modem | 46 | 9.5 |
| 31 | Lady leather boots | 218 | 142.0 | **98** | Aircraft parts | 1 | 0.4 |
| 32 | Cards | 4354 | 776.9 | **99** | Remote control | 422 | 125.7 |
| 33 | One time USE CA | 7048 | 882.9 | **100** | Spares for pack | 113 | 26.8 |
| 34 | Switch | 2689 | 600.3 | 101 | Ladies woven JA | 3763 | 494.4 |
| 35 | Projector V11H65 | 3006 | 600.3 | **102** | Leather gloves | 480 | 95.3 |
| 36 | Footwear | 7139 | 1483.2 | **103** | AC charger | 2248 | 600.3 |
| 37 | Headset | 309 | 105.9 | 104 | Womens kintted T-shirt | 5600 | 1200.7 |
| 38 | Handware | 3186 | 706.3 | 105 | Bare boad | 1702 | 353.1 |
| 39 | Connector | 344 | 55.1 | 106 | Adapter | 2582 | 635.7 |
| 40 | Silencer and SP | 1408 | 600.3 | **107** | Speaker | 1064 | 353.1 |
| 41 | Hardware with | 1013 | 282.5 | 108 | Notebook computer | 9666 | 2024.6 |

(*continued on next page*)

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(*continued*)

| No | Nature of goods | kg | cu ft | No | Nature of goods | kg | cu ft |
|---|---|---|---|---|---|---|---|
| 42 | Thinkpad T440 | 92 | 17.0 | **109** | Ladies pant | 1196 | 122.8 |
| 43 | Woens contton knitted | 2758 | 600.3 | **110** | Data storage devices | 120 | 14.9 |
| 44 | Girls ladies 95 | 91 | 17.0 | **111** | Mitsubishi car audio | 1314 | 492.2 |
| 45 | Medical REFRGERAT | 115 | 38.8 | **112** | Ladies S underwear | 621 | 181.9 |
| 46 | FR. stabilizer bar | 2744 | 318.3 | 113 | Notebook computer | 7590 | 1413.3 |
| 47 | Gift box empty | 708 | 141.3 | **114** | Vibrator motor | 967 | 91.8 |
| 48 | Digital probe | 298 | 70.6 | **115** | TV consoles | 186 | 38.8 |
| 49 | Connector | 764 | 77.7 | 116 | Invisible shield GLASS | 2791 | 579.2 |
| 50 | FR. stabilizer bar | 1372 | 159.1 | 117 | Headphones part | 8496 | 1801.0 |
| 51 | Printed circuit board assembly | 1184 | 313.2 | **118** | Steliant tubing | 2174 | 600.3 |
| 52 | Underwear | 5 | 6.9 | 119 | Womens jacket | 3396 | 706.3 |
| 53 | Camera | 225 | 46.4 | **120** | Stock lot socks | 384 | 76.5 |
| 54 | LED indicator P | 2056 | 525.8 | **121** | Ignition coil | 74 | 17.6 |
| 55 | Plastic injection mold | 508 | 7.1 | **122** | Value control board | 414 | 44.7 |
| 56 | Short arc lamps | 1165 | 236.6 | **123** | Monitor touch | 2889 | 944.3 |
| 57 | Aluminium wheel | 3084 | 560.7 | 124 | Air tools | 1168 | 262.3 |
| 58 | Multi crystalline solar cell | 13,480 | 1689.2 | **125** | Ferrite core | 549 | 68.4 |
| 59 | Icircuit Brkr Box Srve rated | 3193 | 330.0 | **126** | DC motor | 543 | 22.2 |
| 60 | Spent target | 25 | 6.0 | **127** | TFT LCD module | 18 | 6.1 |
| 61 | Screw | 759 | 20.8 | **128** | Ethernet switch | 162 | 55.7 |
| 62 | Global positioning system navigator | 4378 | 520.2 | **129** | Silencer and SP | 756 | 438.6 |
| 63 | Barium titanate | 325 | 31.4 | **130** | Calf hair tote bag | 750 | 211.9 |
| 64 | Plastic products | 2125 | 988.4 | **131** | Monstermesh short | 888 | 264.5 |
| 65 | Laser printer parts | 301 | 130.0 | **132** | Men S knit vest | 668 | 231.7 |
| 66 | Semiconductor parts | 1 | 0.4 | **133** | Headset | 309 | 105.9 |
| 67 | PVC synthetic paper tag | 1130 | 101.5 | Total | | 219,470 | 42,786 |

Note: * the part marked in numbers in bold being the cargo loaded in Scenario 11.

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