[Article title]

Price Setting for Extra-Baggage Service for a Combination Carrier Using the Newsvendor Setup

Abstract

Wide-body aircraft are frequently used to meet upsurges in passenger demand, resulting in the underutilization of the belly-hold capacity on many routes. In the existing literature, investigating this specific underutilization problem has not received much attention from scholars in this field. Therefore, in this paper, we study this problem with two main objectives. First, to propose an Extra-baggage service as a solution to the underutilization problem. Second, to provide the associated prices for the proposed extra-baggage service. For this purpose, we adopt the newsvendor-based pricing model that explores different prices, while combining different amounts of extra-baggage and cargo in the belly-hold space. To demonstrate the potential and feasibility of the proposed service, a numerical simulation has been performed. The simulation includes comparing the expected profit from cargo allocation with the expected profit from the allocation of a combination cargo with Extra-baggage. The simulation results show a significant profit improvement for the airlines, while using the Extra-baggage scheme. This is apparent as the profit increases by 25% over the current excess baggage scheme. Moreover, the results show a double profit improvement in various seasons. This performance echoes the importance of the extra-baggage service being implemented in real practice.

Keywords: Pricing, Newsvendor, Air cargo, Combination carriers, Extra-baggage, Excess baggage, Underutilized capacity.

1 Introduction

In terms of service provision, airlines can be divided into three categories: i) All passenger airlines; providing passenger services, assigning the passengers in the aircraft upper-deck and allocating passenger bags into the aircraft belly-hold, ii) All cargo airlines; these airlines provide only cargo carrying service, and thus, they use only freighter aircraft which transports only cargo, and iii) Combination carriers; they provide both passenger and cargo services (Merkert et al., 2017). Combination carriers can be either Low-Cost Carriers (LCCs) such as Southwest Airlines in the USA, EasyJet in the UK, and Air Asia in Malaysia, or Full-Service Combination Carriers (FSCCs) such as Delta in the USA, Cathay Pacific in Hong Kong, and Lufthansa in Germany. Both FSCCs and LCCs utilize the passenger aircraft belly-hold to carry cargo. They assign passengers to the aircraft upper-deck and allocate cargo to the belly-hold space side by side with passenger checked-baggage.

In regard to passengers, as a common service in all passenger and combination carriers, IATA (2016) expects that the passenger demand will grow from 3.8 billion passengers to almost double by 2035. Thus, the combination carriers have a great challenge in satisfying the rapid passenger demand. This challenge is felt in the limited airport capacity (Evans & Schäfer, 2014), and in constrained staff and fleet capacity (Kölker et al., 2016). One of the potential tools to face the demand upsurge is to replace the narrow-body aircraft with wide-body aircraft. Although wide-body aircraft accommodate a larger number of passengers, they have a larger belly-hold capacity compared to the narrow-body aircraft (Boeing, 2016). This coincides with reports which reveal that the cargo demand is not sufficient to cover the airlines cargo capacity (Air Cargo News, 2016; The Economist, 2016). Consequently, the large space in wide-body aircraft leads to an underutilization problem in the aircraft belly-hold. Moreover, in different seasons, underutilization in the aircraft belly-hold problem occurs and in some other seasons suffer from an over-capacity problem (hot-selling) (Feng et al., 2015). Furthermore, the world freighter usage is expected to increase from 1770 to

3010 freighters, i.e. 70% increase in the period (2016 - 2033), and the aircraft belly-hold utilization does not exceed the 50% as shown in Fig. 1 (IATA, 2017). The low load factor, in turns negatively influences the airline business performance, and the load factor increase enhances the overall saving (Totamane et al., 2014).

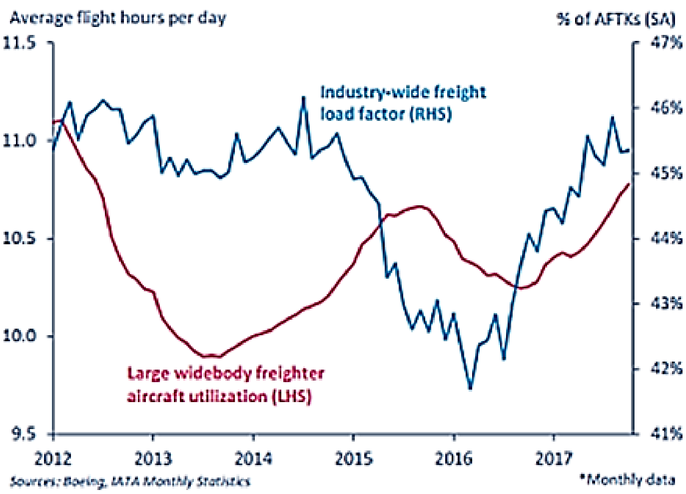


Fig. 1 Widebody freighter aircraft utilization and the relative load factor (Source: IATA Cargo Strategy)

In this paper, we tackle the underutilized belly-hold capacity problem in the combination carriers. As mentioned above, the combination carriers load the passenger checked-baggage and the cargo into the aircraft belly-hold, but the cargo quantities are not sufficient to fill the belly-hold. Also, each airline has a different baggage strategy, and LCCs and the FSCAs also have different baggage strategies. On the one hand, the LCC does not offer baggage in the air-ticket, and the passenger pays for the baggage as an ancillary service. For example, in Easy Jet airline, the passenger pays from 11.56 to 43.7 USD[1] to book baggage of weights from 15 to 40 kg, and it costs 12.5 USD for each excess kilogram over the pre-booked amount. On the other hand, the FSCAs offer checked-baggage to each passenger in the air-ticket. But the full-service combination carriers' strategy sets a checked-baggage limit for each passenger. Additionally, each airline offers different excess baggage schemes for passengers who aspire to more weight.

The recent excess baggage service[2] in FSCCs have different schemes among the airlines. To understand what the excess baggage is, the allowed checked-baggage should be introduced. In this aspect, an airline offers checked-baggage in pieces and/or weight. For example, on a single passenger air-ticket, the allowed checked baggage in some airlines is one-piece of 30kg weight, and some others provide two pieces with 23kg per piece. If the allowed checked-baggage is not sufficient, then the airlines offer different excess baggage schemes for passengers who wish to book more weight. Airlines offer excess baggage in two systems: A Pre-booking system where the passengers can book a limited amount of excess baggage in advance; and the penalty cost system, in which the passenger pays a high penalty cost for each excess unit of weight on the check-in counter. **See Section 3**.

The recent excess baggage prices in many FSCAs are exaggerated. For example, in some airlines, for only one-piece weight, e.g. 23kg, on a certain flight may cost the passenger over 300 USD. The high excess baggage prices cause many passengers to use devious methods to avoid incurring extra-fees for their excess weight (Coffey, 2018). Moreover, the current excess baggage scheme is complicated. This complexity is clear in the frequent change in the pricing policies and the price values. For example, in Cathay Pacific

[1] The USD has been transformed from the Pound Sterling at the standard rate in September 3rd, 2018.
[2] In this paper, excess baggage refers to the current scheme, and Extra-baggage refers to the proposed scheme

(2018a), the pricing policy in July 2018 was to sell the excess baggage in 5kg blocks, but by the end of August, the policy changed to sell the excess baggage in unit weight (kg). The same airline offers the price per excess weight (kg) in the flight leg as 12 USD to passengers who booked their tickets from February 2018 to May 2018, and this price increased by 2 USD for tickets booked after May 1st, 2018. Although the FSCAs provide excess baggage schemes, passengers cannot simply book their needs from the excess baggage over the ceiling decided by the airline (Cathay Pacific, 2018b). This ceiling prevents the passengers who are willing to pay from buying more excess baggage, instead, they either dispose of their belongings or send them via a logistics company. Indeed, usage of the excess baggage scheme by airlines does not help in solving the underutilization problem.

In the aspect of solving the underutilized belly-hold problem, we propose the Extra-baggage scheme to replace the current excess baggage. The Extra-baggage scheme solves the underutilized belly- hold problem by considering the Extra-baggage as a special cargo and relaxing the booking limits for passengers who need more space in the belly-hold.

Airlines already gain profit from offering the excess baggage service. For example, on a worldwide scale, the income from the over-weight bags, excess baggage, and other ancillary services reached almost 82.2 billion USD (Dailyhive, 2017). On the individual scale, Britons are charged more than £3.5 billion annually for their excess baggage (DailyMail, 2017), and the sum of US airlines's profit from excess baggage exceeded 4 billion USD in 2016 (Bureau of Transportation Statistics, 2016). Furthermore, many passengers need an excess baggage facility because of the last-minute souvenir purchasers, and the wrapping service users (Airports International, 2012). In Southern European airports, the majority of wrapping service users come from Africa, Gulf states, Southeast Asia, the Middle East, and Latin America. Additonally, the free trade agreements between the countries concerned facilitate small-business scale in these countries (Trade and Industry Department, 2017), such as the Hong Kong mearchants travelling to South Korea to buy cosmetics (South China Morning Post, 2018). In this case, if these merchants want to gain more profit, they will buy larger amounts of products, and consequently, they will carry heavier baggage to the airport.

In fact, the business of carrying the extra-baggage should be a profitable one. Consequently, many logistics companies provide only an excess baggage carrying service, such as Excess Baggage Company (Excess Baggage Company, 2018), Send Your Bag (Send Your Bag, 2018), and Luggage Forward (Luggage Forward, 2018). Therefore, a simple and feasible Extra-baggage scheme is required to attract passengers to book more space for their extra-baggage. By implementing the Extra-baggage scheme, the airline is expected to share the Extra-baggage logistics companies profit, since passengers who want to transport their belongings can simply book additional space on the flight with the expectation that the belongings will arrive on their flight.

To offer this service, the airlines should take some key decisions, which are premised on answering the next two questions: what is the price of this service? And what are the most related services that can be used as a benchmark to set the new service price? Answering these two questions requires deep understanding of aircraft belly-hold space planning.

Usually, the belly-hold space is divided into different compartments, such as passenger baggage compartment, cargo compartment, and so forth. The cargo compartment has an estimated weight and/or volume capacity. The overall weight including the loaded cargo compartment must not exceed the aircraft MTOW[3](FAA, 2016). Since the under-utilization problem occurs in the cargo compartment, it is suggested that the passengers' Extra-baggage can fill up the cargo compartment.

[3] MTOW is the maximum takeoff weight of the aircraft.

In this regard, airlines use different Revenue Management (RM) techniques. RM is the way to allocate the available demand to the airline limited capacity in order to maximize the profit. Also, it is the method which supports the airline decision to sell the right capacity to the right consumer with correct timing (Sheryl, 2009). In this paper, we discuss the price of the proposed Extra-baggage scheme. For this purpose, and as commonly used in the literature, we adopt the Multi-item newsvendor-based pricing model to include the cargo and Extra-baggage services. We also explore the effect of combining different amounts of Extra-baggage and cargo on the airline's profit. In order to assess the potential of the proposed service, a numerical simulation is conducted.

This paper makes two contributions: First, to the best of our knowledge, this is the first paper which establishes the theoretical basis for the excess baggage pricing scheme. Currently, these schemes are performed by the airline's top management. Therefore, a theoretical model is required to reduce the ambiguity of the current excess baggage schemes. Second, the model makes a modified Extra-baggage scheme by dealing with the Extra-baggage as a special kind of cargo. These significant contributions provide a solution for the underutilized belly-hold space with a known pricing pattern, and thus, the Extra-baggage price can use standard rates similar to the IATA Tact rates. Third, although the combination carriers carry both passengers and cargo, most of the research deal with each sector separately, and thus, the importance of the two sectors differs among researchers (Reis & Silva, 2016), while in this research, we consider that the two sectors are complementary. The advantage of the increase in passenger demand is taken to supplement the unused space in the belly-hold space by the mean of Extra-baggage.

2 Related Works

As mentioned above, the continuous passenger demand boom exposes the airline to limited capacity problems, and such problems in the combination carriers are approached in both the cargo and passenger sectors, so numerous research was conducted to manage the limited capacity. The allocation problem in both passenger (Curry, 1990; Smith et al., 1992) and cargo sectors caught scholars' attention. In this research, although the passenger seating is not within the research scope, their baggage and excess baggage accommodation are of concern. In addition, because the combination carriers allocate the cargo in the passenger's aircraft belly-hold side-by-side with the baggage and the excess baggage. The cargo allocation problem is discussed in this study.

The combination carriers accommodate passengers and their baggage under limited aircraft capacity. The limited capacity is not only on the number of seats on the upper-deck, but also in the aircraft belly-hold, i.e. the air cargo allocation encounters limited belly-hold capacity. To cope with the limited capacity problem, airlines use revenue management techniques (Smith et al., 1992). In this regard, Kasilingam (1997a) discussed passenger and cargo revenue management and showed the difference between them. Also, he asserted the complexities of implementing cargo revenue management. Moreover, he proceeded in cargo revenue management to solve the overbooking model in stochastic aircraft capacity (Kasilingam, 1997b). In addition, Luo and Shi (2006) developed a cargo allocation model for multi-leg problems considering long and short-term contract analysis. This work was not robust enough because it did not consider the cargo dimensionality. Although Amaruchkul et al. (2007) only formulated a single-leg problem, they took the variability of the cargo weight and dimensions into account. Furthermore, they provided a robust comparison between the common FCFS allocation method and the new model. With the increase of the hub-and-spoke system, the need to manage the airline capacity in networks is a persistent need. Levina et al. (2011) constructed a linear programming model to manage the acceptance and/or rejection of the cargo orders for better allocation. The cargo capacity allocation was extended to include the relationship between a single airline and multiple freight forwarders (Amaruchkul & Lorchirachoonkul, 2011).

Amaruchkul et al. (2011) affirmed that the way to optimize the capacity allocation is to develop the suitable capacity contracts between the airline and the freight forwarder. In this regard, researchers designed various contracting models, such as option contracts between the airline and a single forwarder (Hellermann et al., 2013), and the contract between the single airline and multiple freight forwarders (Tao et al., 2017).

Not so long ago, the above studies were carried out to cope with the limited cargo capacity, whereas the current situation is different due to the low cargo demand and the high aircraft capacity (Economist, 2016). The additional space resulting from the use of wide-body aircraft leads to an underutilization problem in the aircraft belly-hold (Air Cargo News, 2016; Boeing, 2016). To solve this problem, Feng et al. (2015) proposed a cargo capacity bundling mechanism on different routes, but their model did not guarantee full utilization of the whole routes' capacity. This is because the allocation balancing does not increase the airline demand. In addition, their model relies on the airlines' power to bind the forwarders to book spaces in underutilized routes, regardless of the forwarders' need for capacity in the underutilized routes. Thus, this solution may worsen the relationship between the airlines and the forwarders.

This research proposes a solution for the underutilized belly-hold space in the full-service combination carriers (FSCCs). The solution suggests the airlines treat the Extra-baggage as a special cargo service. Therefore, Extra-baggage can be allocated into the aircraft belly-hold space, and specifically into the cargo compartment. This entails the airline replacing the current excess baggage pricing scheme with a new Extra-baggage pricing scheme. The new scheme aims to fill the empty space in the cargo compartment, and may be achieved, if the airlines relax the extra-baggage limits for passengers.

Currently, the FSCAs offer limited checked-baggage on the passengers' air-ticket. Wong et al. (2009) studied the optimum baggage limits in the combination carriers. As far as we know, although the researchers did not focus on the baggage and excess baggage studies in the FSCAs, the baggage service received much attention in previous studies of the LCCs.

Unlike full-service combination carriers (FSCCs), Low-Cost Carriers (LCCs) unbundle the baggage from the air-ticket price. Based on weight, they charge the passenger for any checked-in bag, while the full-service combination carriers include the baggage in the air-ticket cost. Most of the research is concerned with LCCs unbundling schemes and studying factors that affect these schemes. For instance, Vinod and Moore (2009) demonstrated the airlines' branding strategy and the impact of unbundling their ancillary services on pricing and revenue management. They used the airline industry to study promotion branding strategies, where some airlines segment their market into different flight classes, and they provide services for different passengers i.e. excessive baggage bundling as an ancillary service with varied prices. Similarly, Garrow et al. (2012) studied US airlines' trend to segregate their airfares into different revenue resources and ancillary services. They reported that the checked baggage is one of the most beneficial resources in the service discrimination trend. However, the study focused only on US low-cost carriers, which is not sufficiently representative of global conditions. Henrickson and Scott (2012) also investigated the effect of segregating checked bag fees on air ticket prices following the dramatic increase in jet fuel prices between 1995 and 2009. They then concluded that separating the baggage fees from the air tickets allows the airlines to decrease their airfares and hence be more competitive and achieve increased profit. Furthermore, Zou et al. (2017) showed that the baggage fees have a potential influence on the airfare and the traffic as well.

The baggage fees are influenced by fuel prices; Barone et al. (2011) studied the effect of changes in jet fuel prices on baggage limits and prices. Further, they used ordinary least squares (OLS) to develop a market model with the aim of estimating the airline's stock returns when changing baggage fees. The results revealed that the checked bag fees of airlines do not affect their competing stock prices, which is correlated with abnormal stock returns. Scotti and Dresner (2015) adopted a three-stage least squares (3SLS) regression method to investigate the significance of baggage fees on passenger demand on some US routes. Their results showed that high baggage fees negatively affect air passenger demand, as shown by Yazdi et al. (2017).

The airline operational performance directly influences the baggage fees. Although the airline reduces baggage mishandling by increasing its fees, passengers did not complain about the increased baggage rates (Scotti et al., 2016). Moreover, baggage is one of the main reasons for flight delays, so the baggage fees policy is an important factor to improve the on-time performance of the flight (Yazdi et al., 2017). Therefore, the delay penalty costs can be minimized.

The most relevant paper to our study was done by Wong et al. (2009). The authors formulated a constrained model in cargo and passengers' regular checked bags in a price dependent newsvendor form. The main objective of this research was to optimize the weight limit for the passenger bags and maintain sufficient space for cargo. Also, they studied the effect of baggage quantity, number of passengers, and bags and cargo costs on the amount of allocated cargo in the belly-hold space. Finally, they recommended that allocating more cargo in the belly-hold space can be achieved by decreasing the space occupied by passengers' baggage. Although this recommendation may achieve the airlines' acceptance in order to increase their profit, it constitutes a burden on passengers who bring over-weight baggage to the airport. These may not be very useful in the current large aircraft capacities and low freight demand.

From the above, it is clear that airlines suffer from unused cargo capacity on different routes, because of the frequent use of wide-body aircraft (Brandt & Nickel, 2018).

The drawback of the antecedent studies is that they were performed on LCCs while passengers' bags in the full-service combination carriers has not received much attention. On the other hand, each full-service has different Extra-baggage pricing schemes. Moreover, as far as we know, there is no published work to manage the Extra-baggage schemes of the full-service combination carriers (FSCCs). This paper aims to develop a revenue management model to set the price for an Extra-baggage scheme in FSCAs.

Additionally, this research takes advantage of the unused space in the cargo compartment to relax the Extra-baggage problem limits and open a weight-based pre-booking system instead of the piece-based system. Furthermore, it investigates the profit airlines make when extending the passengers Extra-baggage allowance. Additionally, it deals with the Extra-baggage as a special cargo service in order to solve the underutilization problem.

3 Excess baggage, Extra-baggage, and cargo

As aforesaid, the full-service combination carriers (FSCCs) provide both passenger and cargo services. Due to the low cargo demand besides the frequent use of wide-body aircraft, some flights depart with unoccupied belly-hold spaces. Thus, this paper is presented to solve this problem by proposing the Extra-baggage scheme to replace the existing excess baggage scheme.

On the one hand, airlines provide two excess baggage options: First, a passenger books one or two additional pieces in advance. Second, the passenger pays for each excess unit weight over the allowed checked-baggage at the check-in counter. For more elaboration, in the current situation airlines proffer from one to two pieces (from 23 to 35kg each), for each passenger on his/her tickets. Therefore, they also offer excess baggage schemes for passengers who may have more baggage over the allowed weight. The weight and the price of these excess baggage schemes vary from one airline to another. Not only do excess baggage schemes differ in terms of pricing and weight allowed, the schemes also differ within the airlines. Moreover, pricing policies of the excess baggage are frequently changed, for instance, excess baggage schemes weights and prices differ with the fare class and vary with the different geographical zones. Furthermore, the excess baggage price may change before and after a certain date.

In Lufthansa, the excess baggage price before 18 April 2018 differed from the price after 18 April 2018 (Lufthansa, 2018). This difference was not only on the excess baggage prices but also in the route classification system. Before April 2018, the pricing was based on two price zones: prices within Europe routes, and prices between the intercontinental routes.After 18 April, on the other hand, the intercontinental routes were split into five new routes. These routes include North Africa, Eastern Mediterranean countries, and Central Asia routes, short intercontinental routes, medium intercontinental routes, long intercontinental routes, and routes from/to Japan. Consequently, the prices on some routes increased and decreased on others. The rise in the price of some routes reached 78 USD over the old rates (200 USD), e.g. the maximum bag price in the intercontinental routes was 200 USD, and it became 230 USD in the medium intercontinental and 278 USD in the long intercontinental routes.

The common factor among all the schemes is the high prices which represent a huge burden on passengers. This burden reaches its peak when passengers go to the airport with over-weight baggage without an advance booking. In this situation, the passenger either pays a very high price for each unit over-weight or dispose of the excess weight, if he/she is not willing to pay. In most airlines, the excess baggage scheme is also limited to one or two pieces over the allowed regular baggage. For example, Lufthansa does not accept a single bag which weighs more than 32kg, and they forward this baggage to the cargo sector (Lufthansa, 2017).

On the other hand, our suggested Extra-baggage service may be considered as a special cargo service, which is proposed to occupy the unused space in the cargo compartment by the passengers' Extra-baggage. By offering this service, a passenger can easily book any number of weight units on the flight, in advance, rather than sending his/her belongings via shipping companies[4]. For this service, the combination carriers offer a new pricing scheme for Extra-baggage, because the current excess baggage scheme is complex and not attractive to passengers. **Fig.1** illustrates a schematic diagram of the difference between the current excess baggage and the proposed Extra-baggage service. The proposed service proffers the Extra-baggage as a special cargo and the Extra-baggage prices are derived based on a chargeable weight-based service. This implies that the passenger can book any additional weight in the same way as in cargo, but at different prices.

The difference between the cargo and the Extra-baggage services is that the Extra-baggage service avoids customer bidding, games, and negotiation. In other words, this service does not entail any brokers, shippers or forwarders. Moreover, in the cargo service, the airline does not have a direct relationship with the single customers, except with big shippers such as car manufacturers, while the Extra-baggage customer is a passenger in the airport of origin. The same passenger receives the Extra-baggage in the destination airport, whereas the cargo consignee at the destination is different from the customer airport of origin. The operations of cargo and Extra-baggage are shown in **Fig. 2**.

[4] Passenger can book Extra-baggage in weight units, from 1kg to *n* kgs., where *n* cannot exceed the cargo compartment capacity.

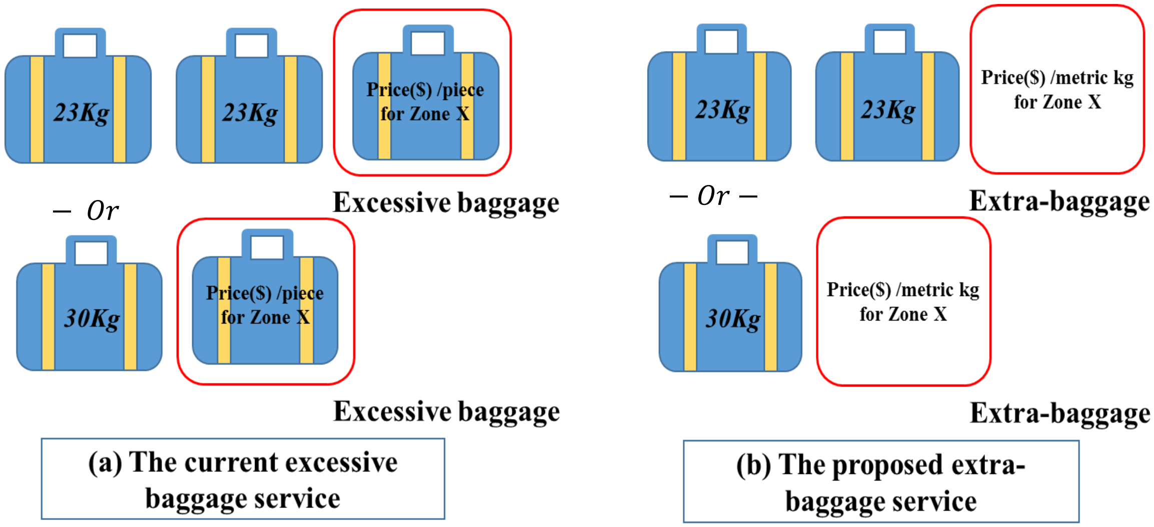


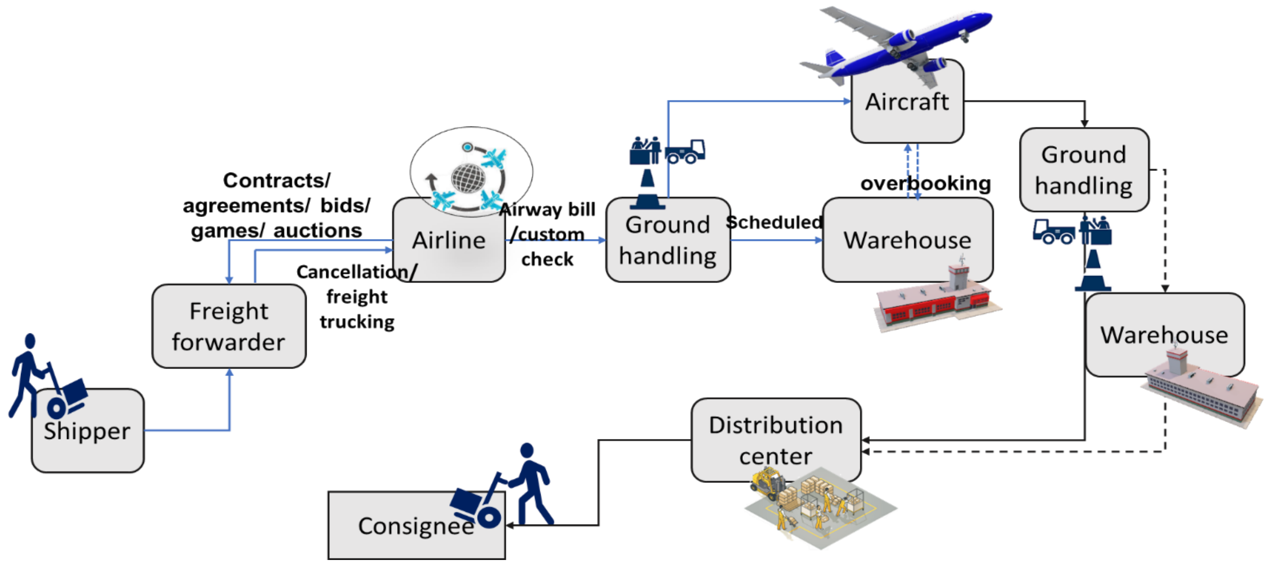
Fig. 2 A schematic diagram compares the current excessive bags service and the proposed Extra-baggage service.

Recently, British Airways (BA) and Fly Emirates implemented two different policies similar to the proposed Extra-baggage service. British Airways offered a new excess-baggage scheme in 2018, but with a limited number of bags, overall ten bags for each passenger, with increasing prices (BritishAirways, 2018). Whereas, Fly Emirates offered three more bags over the allowed baggage on the tickets, 40 USD per kilogram for each excess bag, on the Cairo-Hong-Kong flight. This means that if the Extra-baggage weights 20 kg, it costs the passenger 800 USD, whereas the average price of the air-tickets is 650 USD, and is thus very expensive (Emirates, 2018). Another example is Cathay Pacific; it has a unique excess baggage scheme, because it only allows prepaying in 5 kgs. blocks at a minimum price of 50 USD in the short haul flights.[5]

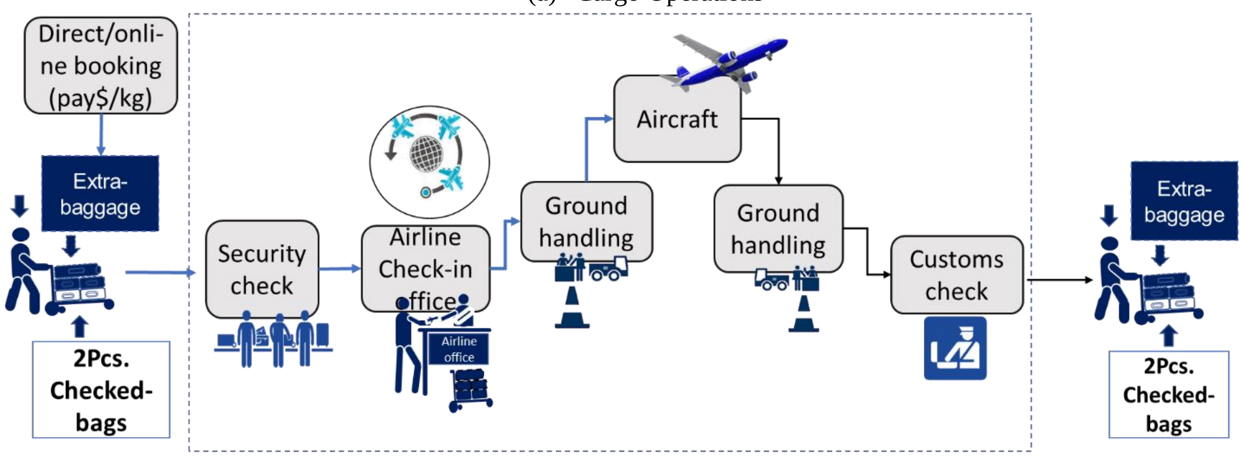
Furthermore, the proposed Extra-baggage scheme considers the cargo demand and the Extra-baggage price change dynamically with the cargo prices. This is because both air cargo and passenger Extra-baggage share the same capacity. Thus, the airline must keep a balance between the two services.

The proposed model has a major difference, in which the model is concerned with passenger bags' safety and reduced mishandling. Furthermore, it is assumed that the airline rejects any Extra-baggage when the capacity of the assigned aircraft is full.

[5] It is necessary to emphasize that these three examples are selected, because it is concerned only with full-service combination carrier FSCC. While in most LCC carriers, the passenger pays for the baggage separately, and as an ancillary service is not included in the air-ticket price. Thus, LCC carriers are not considered in our study.



(a) Cargo Operations



(b) Extra-baggage Operations

Fig. 3 A schematic diagram compares cargo operations (a), and the Extra-baggage operations (b).

4 Theoretical formulations:

4.1 New Extra-baggage scheme

In this section, we develop a price setting model to study the effect of an Extra-baggage service on the expected profit, on the premise that an airline receives the Extra-baggage as a special cargo process beside the traditional cargo service in order to fill the aircraft underutilized belly-hold space. To demonstrate this, let us consider a wide-body aircraft, which is assigned to a single-leg flight, that has a known capacity. The flight comprises passengers occupying the upper-deck, whereas cargo, passengers checked-baggage, and Extra-baggage are contained in the aircraft's belly-hold. Passengers checked-baggage and the cargo with Extra-baggage are allocated in a separate compartment determined by the airline. The newsvendor setup details are discussed in **Appendix A.**

In the definition of market demand, Lau and Lau (1988) considered the demand in a homoscedastic linear regression equation in price. This formula matches the cargo tact rules which define the negative relationship between the demand and prices. So, we apply the linear regression model to the cargo, and thus the Extra-baggage as a special cargo service. The demand functions based extra-baggage price P_e and cargo price P_c are expressed in equations (1) and (2):

$$D(P_e, \varepsilon_e) = a_1 - b_1 P_e + \varepsilon_e \ , (a_1 > 0, b_1 > 0) \tag{1}$$

and,

$$D(P_c, \varepsilon_c) = a_2 - b_2 P_c + \varepsilon_c \ , (a_2 > 0, b_2 > 0) \tag{2}$$

The random variables ε_e, and ε_c for extra-baggage and cargo demand, respectively, are defined in the ranges $[A_1, B_1], [A_2, B_2]$ respectively, where $A_1 > -a_1, A_2 > -a_2$ because the demand in all cases must be positive for the range of prices P_e, P_c , where a_1, a_2 are the regression constants of the additive demand-based price function, and b_1, b_2 are the slopes of these demand functions. As mentioned above, the model is derived to study the effect of combining Extra-baggage and cargo services on the expected profit in the form of a pricing mechanism. So, we characterize the proper optimality condition for the new integrated service. The profit equation can be obtained by subtracting the costs, such as operational and penalties from the revenue, as defined in equations (a3), (a4), and (a5) of **Appendix A**. Equation (3) provides the profit function of the cargo compartment, which involves both the cargo and Extra-baggage.

$$\Pi(X_i, P_i) = \begin{cases} \sum_i (P_i D_i(P_i, \varepsilon_i) - O_i - H_i) \ , & if \ \sum_i D_i \le \sum_i X_i \\ \sum_i (P_i X_i - O_i - S_i) \ , & if \ \sum_i D_i > \sum_i X_i \end{cases} \quad for \ each \ i = e, c \tag{3}$$

where X_i is the offered quantities , O_i stands for the airline incurs an operating cost ,H_i is the leftover cost, and s_i is the shortage cost for each unit of extra-baggage and cargo and D_i is the expected market demand for both extra-baggage and cargo.

The expected cargo price can be calculated as a function of the Extra-baggage price and the overall quantities of cargo and Extra-baggage, as shown in equation (4).

$$P_e = \left([y(P_c) + \varepsilon_c] + a_1 + \varepsilon_e - Q \right) \Big/ b_1 \tag{4}$$

where Q [6] is the chargeable weight capacity of the cargo compartment which is identified by the manufacturer for each aircraft type. The cargo compartment capacity if added to the other aircraft load such as fuel, passengers, and baggage must be less than the MTOW. Therefore, the expected profit can be estimated in terms of the Extra-baggage price and the combination amounts of the cargo and the Extra-baggage.

Lemma 1 The expected profit $\Pi(X_i, P_i)$ which is obtainable from the cargo compartment, is the sum of Extra-baggage's expected profit and the cargo's expected profit, as in equation (5):

$$\sum_{i=e,c} \left[\mathrm{E}[\Pi(X_i, P_i)] \right] = \mathrm{E}\,[\Pi(X_e, P_e)] + E[\Pi(X_c, P_c)] \tag{5}$$

Proof From the definition, the flight profit is the difference between the revenue and the flight costs. For the combination carrier, the revenue resources are obtainable from the number of enplaned passenger's seats plus the sold amount of cargo and the Extra-baggage amount, while the costs can be estimated by different methods. Here, the ASM and ATM[7] cost schemes are preferred and are more suitable. The Extra-baggage costs can be estimated as a percentage of the cost per ASM because baggage operations are concluded in the passenger operational costs. For the cargo compartment, the profit is only estimated from the cargo. The cargo compartment can be filled by both cargo and Extra-baggage. Therefore, the sum of their demands fills the compartment $D(P_e, \varepsilon_e) + D(P_c, \varepsilon_c) = Q$.

[6] According to IATA the chargeable weight capacity can be obtained by the conversion $1m^3$=166.667kg.

[7] ASM, is the Available Seat Mile, and ATM is the Available Ton Mile.

If the properties of the newsvendor form, and the linear relation between the cargo and the Extra-baggage demands are retained, the profit resulting from the cargo compartment can be calculated by the sum of both Extra-baggage and cargo profits. Furthermore, the Extra-baggage demand is highly correlated with the passenger demand. This correlation appears in the relation between the assigned aircraft and Extra-baggage demand. Therefore, the greater the number of passengers, the bigger the assigned aircraft, the greater the tendency to increased Extra-baggage demand. ■

Lemma 1 reveals that the profit of the cargo compartment after adding the Extra-baggage service is the sum of both Extra-baggage and cargo profits. Hence, the Extra-baggage's expected profit may be expressed in equation (6):

$$\begin{aligned}\mathrm{E}\,[\Pi(X_e,P_e)] = {} & P_e[y(P_e)+\varepsilon_e]\int_{A_1}^{X_e} f(\varepsilon_e)d\varepsilon_e \; - c_eX_e - h_e[X_e \\ & - (y(P_e)+\varepsilon_e)]\int_{A_1}^{X_e} f(\varepsilon_e)d\varepsilon_e \; + P_eX_e\int_{X_e}^{B_1} f(\varepsilon_e)d\varepsilon_e \\ & - s_e[(y(P_e)+\varepsilon_e)-X_e]\int_{X_e}^{B_1} f(\varepsilon_e)d\varepsilon_e\end{aligned} \tag{6}$$

and the expected profit of cargo may be expressed as in equation (7):

$$\begin{aligned}\mathrm{E}\,[\Pi(X_c,P_e)] = {} & \left[\left[\left([y(P_e)+\varepsilon_\mathrm{e}]+a_2+\varepsilon_\mathrm{c}-Q\right)\middle/b_2\right][Q-(y(P_e) \right. \\ & \left. +\,\varepsilon_e)]\right]\int_{A_2}^{X_c} f(\varepsilon_c)d\varepsilon_c \; - c_cX_c \\ & - h_c\big[X_c - \big(Q-(y(P_e)+\varepsilon_e)\big)\big]\int_{A_2}^{X_c} f(\varepsilon_c)d\varepsilon_c \\ & + \left(\left([y(P_e)+\varepsilon_\mathrm{e}]+a_2+\varepsilon_\mathrm{c}-Q\right)\middle/b_2\right)X_c\int_{X_c}^{B_2} f(\varepsilon_c)d\varepsilon_c \\ & - s_c[(Q-(y(P_e)+\varepsilon_e))-X_c]\int_{X_e}^{B_1} f(\varepsilon_e)d\varepsilon_e\end{aligned} \tag{7}$$

Although we need to trace the maximum profit by conducting suitable pricing schemes for the integrated cargo and Extra-baggage services, leftovers and shortages impose a larger hurdle on the airline. For a fixed price, the airline may be exposed and lose a vast amount of profit because of inadequate overbooking limits calculations. For instance, airlines sell quantities greater than the cargo compartment capacity to compensate for the shortage due to the no-show and/or order cancelling factors. If the estimated quantity compensation is larger than the real no-show and the cancelation amounts, an overbooking cost is incurred. Conversely, if the real no-shows and cancellations exceeded the estimated quantity compensation, shortage penalty costs are also incurred. So, whatever price the airline sets, there is the chance that the offered quantity will either exceed or not satisfy the expected demand. Equation (8) expresses the expected loss in profit when the allocated quantities do not meet the demand (Thowsen, 1975).

$$\begin{aligned}\mathrm{L}(\mathrm{X}_i,P_i) = {} & h_e[X_e - D(\varepsilon_e,P_e)]\int_{A_1}^{X_e} f(\varepsilon_e)d\varepsilon_e + h_c[X_c - D(P_c,\varepsilon_c)]\int_{A_2}^{X_c} f(\varepsilon_c)d\varepsilon_c \\ & + s_e[D(P_e,\varepsilon_e)-X_e]\int_{X_e}^{B_1} f(\varepsilon_e)d\varepsilon_e + s_c[D(P_c,\varepsilon_c)-X_c]\int_{X_c}^{B_2} f(\varepsilon_c)d\varepsilon_c\end{aligned} \tag{8}$$

In this regard, the airline wishes to maximize the expected profit in (6) and (7) with respect to Extra-baggage prices P_e, and the Extra-baggage and cargo quantities X_e, X_c.

Lemma 2 The maximization of the expected profit function will occur at the values of P_e^* when the partial differentiation of the overall profit function $\mathrm{E}\left[\sum_{i=e,c}[\Pi(X_i, P_i^*)]\right]$ with respect to P_i equals zero.

$$\partial \mathrm{E}\left[\sum_{i=e,c}[\Pi(X_i, P_i^*)]\right] \Big/ \partial P_i = 0 \quad \text{, for each } i = \text{("price TRENDS," 2015).} \tag{9}$$

Proof: For the common newsvendor setting, the expected profit for the linear price-based model is concave and differentiable over the price. Therefore, the maximum expected profit of the cargo service is obtainable from equating the first derivative with respect to the cargo price to zero, $\partial E[\Pi(P_c^*, X_c]/\, \partial P_c = 0$, and the same for the Extra baggage service $\partial E[\Pi(X_e, P_e^*]/\, \partial P_e = 0$.

From Lemma 1, the expected profit of the combination Extra-baggage and the cargo is linearly combination in the Extra-baggage price such that $\mathrm{E}\left[\sum_{i=e,c}[\Pi(X_i, P_e^*)]\right] = E[\mathrm{U}(X_e, P_e] + \alpha E[\mathrm{U}(X_c, P_e]$.This holds the concavity and the differentiability property of the combination function with respect to the Extra-baggage price. ■

In our model, we are concerned with estimating the optimum Extra-baggage price that can be calculated from (3). Without loss of generality, equation (3) can be switched between Extra-baggage and cargo prices. Regarding the demand distribution, Swan (2002) stated that the airlines demand distribution can be a mix of Normal and Gamma distributions. Therefore, for any values of X_e , X_c , if the two random variables of the Extra-baggage and the cargo are normally distributed $\varepsilon_e \sim N_1(\mu_e, \sigma_e), \varepsilon_c \sim N_2(\mu_c, \sigma_c)$, respectively, the maximum expected profit can be obtained with respect to Extra-baggage price through equations (10) and (11):

$$\begin{aligned}\partial \mathrm{E}[\Pi(X_e, P_e^*)] \Big/ \partial P_e &= 2b_1 P_e^*[F(X_e) - F(A_1)] + [a_1 + h_e b_1 - b_1]F(X_e) \\ &\quad - (a_1 + h_e b_1 + X_e)F(A_1) - X_e + \mu_1 - \sigma_1 G(X_e) + (X_e + b_1)F(B_1)\end{aligned} \tag{10}$$

and

$$\begin{aligned}\partial E[\Pi(X_c, P_e^*)] \Big/ \partial P_e &= \left[(2a_1 b_1 - 2b_1 P_e^* + a_2 b_1 + 2b_1 - 2b_1 Q) \Big/ b_2 + b_1 h_c\right][F(X_e) \\ &\quad - F(A_1)] + {}^{2b_1}\!/_{b_2}\, (\mu_1 - \sigma_1 G(X_e) - X_e)[1 - F(X_e) + F(A_1)] \\ &\quad - {}^{b_1}\!/_{b_2}\left[F_{\varepsilon_c}(X_c) - F_{\varepsilon_c}(A_2)\right] + s_c b_1[F(B_1) - F(X_e)] \\ &\quad - {}^{2b_1}\!/_{b_2}\, X_c[1 + F(B_1, B_2) - F(X_e, X_c)]\end{aligned} \tag{11}$$

where $G(\varepsilon_e)$ is a standard value that can be estimated through equation (12) and its value can be obtained through standard tables (Silver & Peterson, 1985).

$$G(X_e) = \int_{Xe}^{\infty} (\varepsilon_e - X_e) f(\varepsilon_e) d\varepsilon_e \tag{12}$$

Proposition 1 The optimal price P_e^* value can be obtained by equating the sum of equations (10) and (11) to zero.

Proof To prove this proposition, there are two cases that should be discussed; (i) there is no relation between the Extra-baggage and the cargo services, (ii) the Extra-baggage and the cargo are directly related

(i) In this case, for fixed Extra-baggage and cargo quantities $E[\Pi(X_i, P_i)] = U(P_e, P_c)$ such that cargo and Extra-baggage is not related. Thus, $\partial E[\Pi(X_i, P_i)] \big/ \partial P_e = {}^{\partial U_e}\!/_{\partial P_e} + {}^{\partial U_c}\!/_{\partial P_e}$, but ${}^{\partial U_c}\!/_{\partial P_e} = 0$, and

$\partial E[\Pi(X_i, P_i)] / \partial P_e = U'_e$. On the other hand, $\partial E[\Pi(X_i, P_i)] / P_c = \partial U_e / \partial P_c + \partial U_c / \partial P_c$, and $\partial U_e / \partial P_c = 0$, and, $\partial E[\Pi(X_i, P_i)] / \partial P_c = U'_c$, and hence, the Extra-baggage price is not affected by the cargo, and thus, the cargo and the Extra-baggage are not directly related.

(ii) In the second case, the proof of Lemma 1 establishes the linear relationship between the cargo and the Extra-baggage demands changes the profit function $\Pi(X_i, P_i)$ from a function of the quantities and prices of both Extra-baggage and cargo to a function of solely cargo and Extra-baggage quantities and Extra-baggage price, so that $\Pi(X_i, P_i) = U(X_i, P_e)$. From Lemma 1, $\sum_{i=e,c}[E[U(X_i, P_e)]] = E[\Pi(X_e, P_e)] + E[\Pi(X_c, P_e)$, and Lemma 2 showed that both expected profit functions with respect to Extra-baggage and cargo prices are differentiable over the Extra-baggage price. Therefore, obtaining the maximum expected profits in terms of optimum Extra-baggage prices holds when $\partial \sum_{i=e,c}[E[U(X_i, P_e^*)]] / \partial P_e = 0$. ■

Before discussing the model, we first discuss some considerations. For example, the model represented in the above equations is the most commonly used in the literature as a revenue management tool. These tools entail that the space specified in an aircraft's belly-hold in certain flights is perishable. The airline may try to reduce the expected leftovers or the expected shortage quantities to minimize the penalty costs. The expected loss function in (8) then plays a crucial role in airline pricing decisions. We, therefore, need to examine the proposed model and compare the expected profit from the new Extra-baggage scheme and the current excess baggage. The current excess baggage scheme is discussed in the next subsection.

4.2 Current excess baggage practice

The current excess baggage practice in the majority of airlines is to segment the flight routes into different zones. The airlines rate the excess baggage between the different zones either by a piece of baggage and/or by unit weight of the excess baggage. This pricing scheme can be formulated as below:

- Let Z is the set of routes in a geographical zone, indexed by i (Origin), and j (Destination) where $i \in \{1, 2, 3, \dots\}$,and $j \in \{1, 2, 3, \dots\}$, where $i \neq j$.
- P_{ij} is the price to carry a unit weight from Origin i to Destination j.
- P'_{ij} is the price to carry one piece of baggage from zone i to zone j.
- N is the number of bags (piece) for a single passenger.
- M is the number of excess baggage weight units.
- k is the number of passenger who book excess baggage in advance, where $k \in \{1,2,3, \dots, K\}$. where K is the total number of seats on the aircraft[8].
- l is the number of passengers who bring overweight baggage where $l \in \{1,2,3, \dots, K\}$.

The airline revenue from the excess baggage (EBR) in flight leg (ij) can be calculated as in equation (13),

$$EBR = \sum_{k=1}^{K} (NP_{ij})_k + \sum_{l=1}^{K} (MP'_{ij})_l \tag{13}$$

It is noted that some airlines have different pricing policies. For example, the price of the first bag is different than the next n bags. Therefore, the excess baggage price in flight leg (ij) is; $NP_{ij} = p_1 + np$, for $n = (0,1, \dots, \varkappa)$, where $\varkappa$ is the maximum allowed number of excess bags.

[8] Number of seats differs among the different aircraft models.

Because the excess baggage service is received with the regular checked-baggage and they need almost the same operations, the excess baggage cost (EBC) can be calculated as a function of the cost per available seat (CAS),

$$EBC = \gamma k(CAS) \tag{14}$$

where γ is the percentage of excess baggage cost out of the (CAS). Hence, the total excess baggage profit (EBP) is estimated by equation (14),

$$EBP = EBR - EBC \tag{15}$$

Each airline puts its own excess baggage constraint either in the number of pieces or in the number of weight units in each zone. Moreover, the major difference between the current excess baggage and the Extra-baggage scheme is that the profit of the current excess baggage is added to the passenger profit, while the Extra-baggage in the new scheme profit is loaded to the cargo compartment profit.

5 Numerical Analysis and Discussion

In the rest of this paper, numerical analysis is conducted with two main objectives. First, to investigate the cargo /Extra-baggage combinations on the expected profit of the proposed model. Second, to examine the profit improvement over the old excess baggage scheme. In order to achieve these objectives, it is noteworthy that constraints (a1) and (a2) are given to control the cargo compartment capacity by linear (inequalities) relationships in terms of weight and volume. However, to keep the model calculations simpler, firstly, we consider that the booking control is fixed, i.e. without allocation limits, for both Extra-baggage and cargo. Secondly, the analysis is only concerned with a single fare class; for example, i.e. economy class. Thirdly, the analysis also excludes the routing changes in Extra-baggage and cargo densities, and weight /volume ratio.

5.1 Cargo and Extra-baggage cost, price, and demand

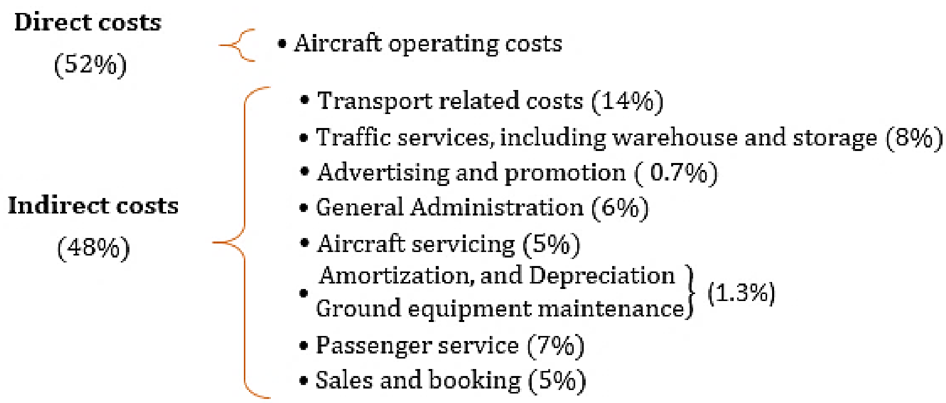
In order to make the analysis of our model non-trivial and manageable, the individual flight cost analysis of Tsai and Kuo (2004) was implemented with some tolerance to fit the proposed model. In this regard, data was collected from a northern American combination carrier A. This airline uses wide-body aircraft (B787-9). Based on the specifications of this aircraft in **Table 1,** we estimated the Extra-baggage unit costs and cargo unit costs for a selected route (X-Y).

Table 1 Aircraft B787-9 specifications

Characteristics	MTOW(kg)	Maximum fuel capacity (US gallon)	Range (nm)	Freight Capacity(kg)
Value	254000	33379.72	7800	17,942

From this standpoint, the travelled distance between the origin X and destination Y is approximately 6000 nm. The airline annual reports in 2014 reveal that the average direct operating cost per ATM was 0.390 USD, and the indirect unit cost was 0.388 USD per ATM. On the Extra-baggage service, because it is planned to replace the current excess baggage scheme, the Extra-baggage costs can be added to the passenger costs. The Extra-baggage costs are almost the same as the regular checked baggage, which costs (8 -14)% of the unit passenger cost (ICAO, 2017). The Boeing 787-9 aircraft unit cost is 7.33 US cents per ASM.

For penalty costs, Chao and Hsu (2014) and Reis and Silva (2016) divided the flight operations costs into direct and indirect costs, as shown in **Fig. 3**. The direct costs can be variable; based on the traveled distance and fixed costs which are incurred regardless of the traveled distance. As formulated in the model, the airlines incur two contradicting penalty costs; first the shortage, which occurs when the sum of offered quantity from the Extra-baggage and the cargo is less than the real market demand of these two services. The shortage costs equal to the fixed costs per unit cargo and Extra-baggage, because the flight fixed cost is incurred regardless of the amount of cargo and/or Extra-baggage in the cargo compartment. The flight fixed costs are approximated to 57% of the overall flight operating cost. On the other hand, the airline offloads the excess cargo and/or Extra-baggage costs. The offloading cost is the sum of warehousing cost (50 US cents/kg), and delay cost penalty (92 US cents/kg).



**Source*: Based on Federal Aviation Administration (FAA) benefit-cost analysis (2016).

*Fig. 4 Direct and indirect flight costs**

Next, we collected three months cargo demand from the same airline A on route (X-Y). The freight maximum demand is 470 tonne, and the minimum demand is 28 tonne. Because it is a combination carrier, it plans the demand for the freighters, such as Boeing 747-400, and Boeing 767-800. The rest of this cargo is allocated in the belly-hold space of the passenger aircraft, Boeing 787-9. In order to estimate the demand function that represents the real demand, a linear regression analysis is conducted. **Table 2** shows the regression results summary, which reveals that more than 85% of the data fits the developed regression model. Furthermore, the P-value is less than the significance level[9] of our experiment, which means that price as an independent variable is statistically significant. The linear regression model describes the empirical cargo demand with coefficients $a_2 = 42940$,$b_2 = 4078$.

Table 2 Regression analysis results Summary

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1775.42	85.86%	85.79%	85.59%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	42940	945	45.43	0.000	
Prices	-4078	114	-35.79	0.000	1.00

[9] The significance level in this model is 0.01

Moreover, the demand functions normality test in the form of the normal probability plot shows that the demand-based price is homoscedastic, see **Fig 4**

On the other hand, the proposed scheme is not yet implemented, and it does not make sense if the current pricing scheme for the excess baggage is used to estimate the demand function of the Extra-baggage service. In this connection, we studied the main factors that affect the Extra-baggage demand-based price function.

As aforementioned, the Extra-baggage scheme is treated as special cargo, but its customers are the same passenger.

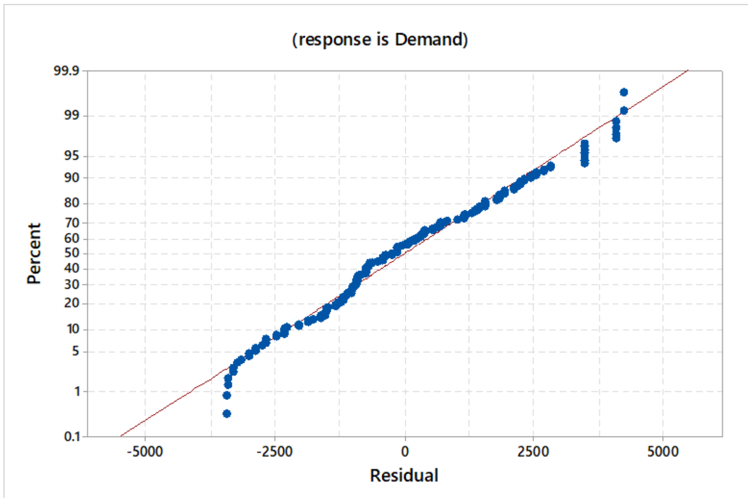


Fig. 1

Fig. 5 Normal probability plot of the cargo demand

Therefore, the Extra-baggage demand is different from the cargo demand, but metaphorically the cargo demand function is used as a reference to the Extra-baggage demand. This is because the cargo and Extra-baggage services share the same compartment, so they complement each other. Thus, we studied the effect of demand function coefficients on the cargo compartment profit. The results are shown in **Fig. 5.**

The cargo compartment profit decreases exponentially with increasing price coefficient b_1. On the other hand, the Extra-baggage price increases dramatically when b_1 decreases. In this regard, we selected the mid-range values of b_1, and a_1 to be 2000 and 50000, respectively.

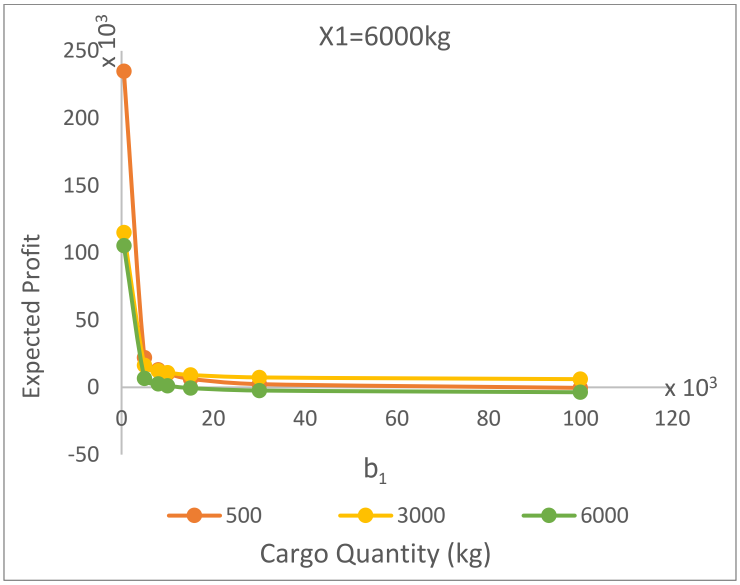


Fig. 6 Effect of b₁ on the profit

The air cargo price (p_c) is determined with reference to the International Air Transport Association (IATA) Tact rules (IATA, 2009). The Tact rates of the (X-Y) route have a decreasing price for each weight level, thus, the more the booked cargo, the lower the unit price. Moreover, a Tact rules use chargeable weight analysis. Chargeable weight is the maximum value between the gross and the volumetric weight, and the cargo price is estimated from equation (16)

$$w_c = \max(w_{gc}, v_c u) \tag{16}$$

where w_c is the unit cargo chargeable weight, w_{gc} is the unit cargo gross weight, $v_c$is the unit cargo volume, and u is the volumetric weight convertor, based on IATA conversion values. Finally, based on the cargo price, the Extra-baggage prices are estimated using equation (4).

5.2 Simulation results

5.2.1 Extra-baggage – Cargo results

Using data from the previous subsection, simulation analysis is performed to study the expected profit of the cargo compartment as a result of combining the Extra-baggage and cargo quantities by operating the analysis based on equation (7). The experiments parameters are shown in **Table 3**.

Table 3 Experiment input parameters in route (X-Y) and assigned Boeing 787-9 aircraft.

PARAMETERS	VALUES
$\boldsymbol{P_c}$	(12.89, 9.89, 8.88, 8.02, 7.16) USD
$\boldsymbol{X_c}$	(0; 500; 3000; 5000; 10000; 15000; 17000) kg
$\boldsymbol{X_e}$	(0; 500; 3000; 5000; 10000; 15000; 17000) kg
CASM[10]	0.0733 USD

Note that the cargo price P_c is extracted from the IATA tact rates for the selected route (X-Y). Furthermore, the quantities of the cargo and the Extra-baggage are assigned such as to meet the aircraft capacity. Moreover, the selected quantity combinations of Extra-baggage and cargo allows us to study the expected profit when the cargo compartment is fully occupied by either cargo or Extra-baggage.

Fig. 6 shows the relationship between the expected profit and the cargo quantities for different cargo prices when the Extra-baggage quantity is fixed. The chart reveals that the expected profit of the cargo compartment decreases with the increase of cargo prices. Moreover, for each individual cargo price, the maximum profit is obtainable from the minimum price. This is because the law of demand states that the lowest cargo price means that cargo demand is very high. Consequently, the airline should impose a very high price for the Extra-baggage service. The profit will then increase because of the Extra-baggage amount which is added to fill the remaining space in the cargo compartment. From equation (4), the lowest cargo price causes the Extra-baggage price to greatly increase, which consequently increases the compartment profit. In this regard, the combination of the cargo and the Extra-baggage affects the profits. In the case that the passengers pay for the high Extra-baggage, it will greatly increase the airline profit with more flexible capacity planning between the cargo and the Extra-baggage.

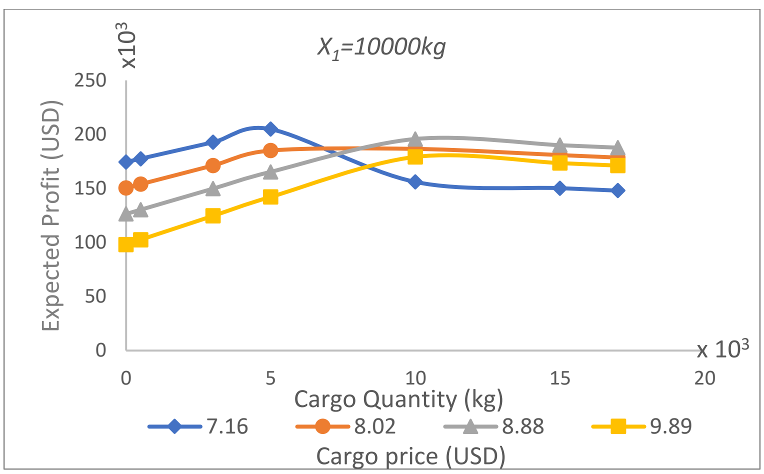


Fig. 7 The expected profit when combining different cargo quantities to certain Extra-baggage quantity for different cargo prices.

The increase in cargo price leads to a decrease in Extra-baggage price, which actually comes from the demand for both Extra-baggage and cargo in different seasons. Usually, the cargo demand is not fixed over the year, and as there are many products and services, the air cargo service has different peaks or seasons. Thus, the combination of Extra-baggage and cargo contributes roughly to Extra-baggage price discrimination. For more elaboration, the law of demand states that an increase in cargo demand leads to a decrease in prices. In this connection, the underutilized belly-hold problem most likely occurs when the demand for cargo is insufficient to fill the aircraft belly-hold, so its price should be high. Therefore, airlines

[10] CASM is the cost per available seat mile.

can impose a low price for the Extra-baggage to attract more passengers to use the service. When the cargo demand is high, the Extra-baggage price should be high as well.

Moreover, the expected profit decreases gradually after the sum of the allocated Extra-baggage and cargo quantities reach the full cargo compartment capacity. The profit drops because the overbooking level is very high, so the airline will offload the overbooked quantities and load them on the next flight. Thus, the airline needs to pay two different costs; a penalty cost for the passenger because of the delay, and a stocking costs at the airport for the offloaded cargo, and/or Extra-baggage.

The expected profit change under the effect of the combination of Extra-baggage and the cargo quantities to fill the underutilized space is shown in **Fig. 7**.By looking at **Fig.7**, we can see that, by fixing the cargo price and making different combinations between the Extra-baggage and the cargo quantities, the expected profit increases linearly until reaching a turning point, and then it drops gradually. Furthermore, once again the expected profit is influenced by the combination Extra-baggage and cargo quantities. The maximum profit, in this case, is obtainable from maximizing the Extra-baggage quantity.

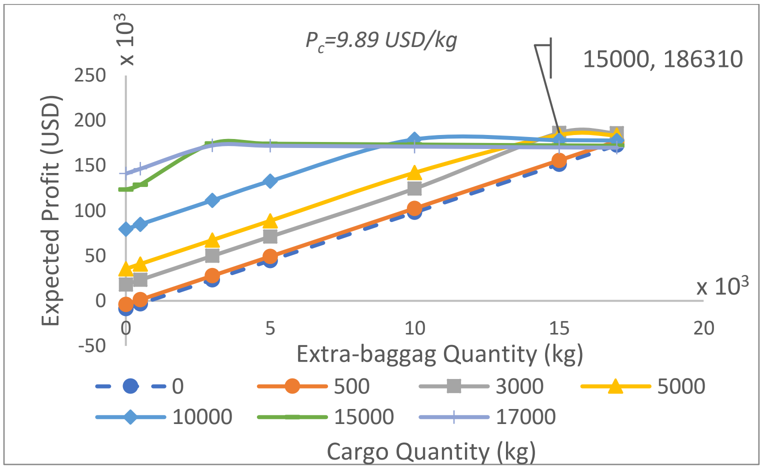


Fig. 8 Reflected changes in a cargo compartment expected profit for the different combination in Extra-baggage and air cargo under fixed cargo price.

The cargo quantities 0 and 500 are exceptional cases, where there is no profit, and the cargo compartment cost is higher than the revenue gained. In these two cases, the effect of the aircraft underutilization problem appears clearly. The airline incurs the passenger flight fixed costs regardless of the cargo compartment utilization of Extra-baggage and excess baggage.

5.2.2 Extra-baggage and excess baggage

In this section, we discuss the difference between the new Extra-baggage scheme and the existing excess baggage scheme in airline A. The excess baggage scheme in airline A follows the piece-based option. At most, ten excess bags are permitted, with a maximum of 23 kg per bag. Even though the airline theoretically allows the passenger to book a maximum ten of excess bags, it may reduce the number of these bags, if the compartment is only sufficient to transport regular checked-baggage. They offer an option to accept the excess baggage, but it will be scheduled to the next flight.

To keep the analysis consistent with the same Boeing 787-9 aircraft, the excess baggage profit (EBP) in route (X-Y) is calculated by equations (13), (14), and (15). The input parameters for the model includes the cost per available seat mile, the traveled distance, seating plan in the airline, (total number of seats) which are designated in the aircraft, and the maximum acceptable weight of excess baggage (23kg).

The Extra-baggage model has been adapted to compare with the excess baggage model. The Extra-baggage prices are estimated with reference to the cargo Tact rates (IATA, 2009). The Extra-baggage analysis ignores the cargo combination and the profit are obtained from the Extra-baggage only, as shown in Proposition 1. It is worth mentioning that the description of the Extra-baggage service as a special cargo service solves the cost per piece and/or weight dilemma. In this regard, the passenger will be charged for the Extra-baggage using the IATA chargeable weight rule (footnote 6), similar to equation (16). **Table 4** represents the comparison between the excess baggage profits with a fixed price for each piece on route (X-Y) and the Extra-baggage scheme profits.

The first and third columns give the core difference between the excess and the Extra-baggage schemes. The excess baggage amounts are counted by the number of pieces. For example, a 220-piece combination is obtained from 40 passengers. On the other hand, the Extra-baggage scheme is offered based on unit weight, for instance, 5060 kg, equivalent to 220-piece in the excess baggage scheme, and can be booked from any number of passengers on the flight. The Extra-baggage prices are obtained from the cargo Tact rates, and the Extra-baggage price varies when the demand changes. The results show that the airline profit increases if the flexible Extra-baggage pricing scheme is implemented. Moreover, the cargo compartment profit resulting from increasing the Extra-baggage quantity is greater than the resulting profit from increasing the excess baggage quantity. In more detail, for cargo price of 9.89 USD, the profit from 5060 kg of Extra-baggage is less than its equivalent excess baggage by almost 9.6%, while the profit improves gradually when the Extra-baggage amount increases. The Extra-baggage profit surpasses the excess baggage profit by 25.3%. However, this increase in the profit depends on our model assumptions, i.e. Extra-baggage model is performed on a particular aircraft, a certain route, and IATA cargo prices in this route. The change of these parameters may either increase or decrease Extra-baggage profits. For example, the aircraft type affects the cost function which lead to an indirect change in the flight profit (FAA, 2016).

Also, the different cargo price range in the selected route affects the airline profit as it is revealed in the four columns (7.16- 8.02- 8.88- 9.89) in **Table 4**. It means that the change in cargo price implies that the cargo demand changes, and in turn the Extra-baggage price is sensitive to the change of cargo demand, i.e. when the cargo demand increases, the Extra-baggage price is raised to decrease the demand, and of low cargo price is imposed. This reflected in the high super high profit in the cargo price 7.16. As an example of the high cargo demand routes, the growth of e-commerce between Europe and the Asia Pacific region leads to increase the cargo demand in these routes. So, the Extra-baggage price in those routes will be very high in order to reduce its demand (IATA, 2018).

Table 4 Profits from Extra- baggage compared with current excess baggage scheme

Excess baggage		**Extra-baggage**					
		equivalent weight (kg)	Cargo price[11] (USD)				
No. of pieces	**Profit (USD)**		7.16	8.02	8.88	**9.89**	**(9.89) Profit difference %**
			Profit (USD)				
220	**34969**	**5060**	78334	63615	48896	**31610**	**- 9.6**
275	43712	**6325**	98835	81506	64177	43826	0.3
550	93782	**13570**	201340	170960	140580	104900	11.9
590	87424	**12650**	216250	183970	151690	113790	30.2
675	107293	**15525**	247930	211620	175310	132670	23.7
700	111266	**16100**	257250	219750	182260	138220	24.2
750	**119214**	**17250**	275890	236020	196150	**149320**	**25.3**

On these routes, if the passenger is willing to pay for the excess weight at a high price, these prices surpass the overbooking penalties. However, this is not expected to happen because the price of extra-baggage in these routes increases exponentially. These results are compatible with those of (Shaban et al., 2018) in estimating the Extra-baggage price with different cargo demands. Furthermore, each row in Table 4 consists of the Extra-baggage profit for different cargo prices. Regardless of the demand, the profit resulting from the Extra-baggage is always higher than the profit from the excess baggage. The profit changes only in the last price 9.89, and this is reasonable because the Extra-baggage service targets the periods of low cargo demand. Furthermore, comparison between the Extra-baggage and the excess baggage would not be fair in case of the high cargo demand, because the prices for Extra-baggage are very high. For example, the profit from the Extra-baggage at a cargo price of $7.16/kg -high cargo demand- gives a jump of 130% over the profit from the same amount of excess baggage services. These results are theoretically reasonable, but practically it is very difficult to achieve because the passengers will not be able to pay the exaggerated price.

5.3 Managerial Insights

combination carriers work in two business formats: First, Business to Customer format, B2C; the airline sells the Extra-baggage service to each individual passenger. Second, Business to Business format, B2B, the airline sells the aircraft capacity to freight forwarder companies. Regarding B2B, it requires complicated operations between the airline and the freight forwarders, including negotiations, bidding, tenders, and contracting. B2C, on the other hand, bypassing all the previous complicated operations, as it imposes different pricing strategies on individual customers.

Because the airline uses the B2C format to sell the Extra-baggage, it can flexibly move between different pricing strategies, as follows:

- The airline may use the cost-based pricing strategy since it is one of the most common strategies. However, this strategy is difficult to be implemented because airline cost analysis is still not well studied, and it may cause inaccurate calculations. So, if the airline has a strong cost analysis system, the selling price of Extra-baggage unit may equal the sum of cost and profit of each unit.

[11] The cargo prices have been nominated from IATA Tact rates for the same flight in route (X-Y). and the extra-baggage is estimated by equation (4), the extra-baggage price in inversely proportional to the cargo price, and hence, the highest cargo price, gives the lowest extra-baggage price.

- The airline may conduct price differentiation for different passenger classes. In this case, the price and the booking amount will be assigned differently for each class.
- The airline may also implement pricing based on operations. Therefore, the Extra-baggage pricing will be strongly correlated to the cargo service. This may affect the pricing strategies by changing the prices in different seasons. However, the cargo business is a complex one, but it still provides a higher transaction as a B2B format. Thus, the price of Extra-baggage may rely on the cargo demand. For instance, in some seasons, the cargo demand is high and the price drops, and thus, the airline is recommended to impose high Extra-baggage prices to minimize its demand.

As the Extra-baggage is designed to be allocated in the cargo compartment, the planning process of the cargo should be affected by the Extra-baggage, because of the random weight and volume of Extra-baggage and cargo, which cannot be controlled. Thus, the airline will need to adjust the cargo plans with respect to the Extra-baggage. During the cargo seasons, some routes will suffer an over demand. Therefore, the airline should find flexible scheduling and planning approaches to take advantage of the high cargo demand with low price and the consequent high price of Extra-baggage which lead to higher profits. Furthermore, the Extra-baggage may take advantage of the Baggage Improvement Programme (BIP) to follow the passenger regular baggage processes (IATA, 2010). Thus, it will not affect the cargo processing which is separately performed.

The Extra-baggage scheme may provide a good reason for a passenger to choose the airline because of his/her need for this service. Consequently, a new segment of passengers will be added to the passenger demand. Therefore, the passenger load factor will be increased. Furthermore, the passenger demand growth will lead to price decrease.

In this paper, the underutilization problem is tackled by the proposing and formulating the Extra-baggage service. Other solutions may be proposed, such as lowering the cargo rates to attract more demand. This hypothesis is not reasonable because of the nature of the cargo business which needs much negotiation and gaming with the freight forwarders. Moreover, air transportation has many other rivals such as shipping and ground transportation, so even if the air freight rates are lowered, the increase in demand will not cover the capacity (Freightos, 2018).

We need to emphasize again that this research proposes the Extra-baggage scheme of the full-service combination carriers, and it is not developed to cancel the checked-baggage. On the other hand, the low-cost carriers (LCCs) allocate zero space for checked-baggage.

6 Concluding Remarks

This research proposes price setting for Extra-baggage service for combination carriers. Indeed, this service suggests that airlines should offer more prepaid space to their passengers. In addition, this service is supposed to take advantage of the rapid increase in passengers over the years. Due to this increase, airlines prefer to use wide-body aircraft with a large belly-hold, causing the problem of non-used space on certain routes. Extra-baggage service is our suggestion to solve this problem, which will make it possible for passengers to order Extra-baggage spaces when they have additional bags. To achieve the aim of the study, we adopt the newsvendor model to set the Extra-baggage prices combination with cargo prices. The model is derived for both Extra-baggage and cargo demand as a function of price. The cargo demand function is transferred to a function of Extra-baggage price. This is achieved by using a linear relationship between the cargo and Extra-baggage through the aircraft capacity, where the total flight demand is assumed to be equal to the aircraft capacity. The model illustrates that the cargo and Extra-baggage are complementary services, and they are jointly used to decide the expected cargo compartment profit.

The advantage of the new service proposed in this study lies in the smoothness and easiness of processing the Extra-baggage. That is, the passenger gets to make his/her order by himself/herself and gets to bring his/her items directly to the flight. Consequently, complicated procedures are avoided as frequently happens in cargo services. Also, it is our position that there is a high likelihood that an airline that applies this new service will attract more passengers. The new service is likely to attract new customers, who need more space, while at the same time supporting its loyal customers. Eventually, we believe that the Extra-baggage service is easy to be implemented because it does not need complex procedures compared to regular cargo services. Moreover, it is a profitable tool, so airlines should offer the proposed service to help in maximizing profits.

Although the change of cargo price can capture the network effects, the numerical results have been studied for a single-leg flight which limits our study. At the network scale, the problem changes, where not all routes experience the underutilization problem, especially seasonally. In various seasons, there are two contradicting effects on the network scale; first, some routes become hot-selling because the demand exceeds the route capacity. Second, the other routes have an underutilization problem because the capacity utilization does not exceed 50%. This unbalance between the different routes in the network, affects the Extra-baggage pricing strategies. We plan to tackle this problem in the future.

A further investigation in the future will involve conducting a market survey for the proposed Extra-baggage service. The forecasting models by Li and Trani (2014); (Nieto & Carmona-Benítez, 2018) may be used as guidance studies for checking the validity of using the PAX numbers and the PAX demand as determinants of the Extra-baggage demand. The next step will be conducting a market study for this Extra-baggage scheme to investigate suitable price policies for the Extra-baggage service and examine the effect of seasonality on the offered prices. Because the Extra-baggage service has not yet adopted in the industry, we cannot forecast its demand. Hence, it is necessary to deploy advanced statistical approaches and optimization techniques to tackle the problem of demand forecasting. Moreover, we believe that the used parameters according to our model assumption has a direct effect on the airline profit, if it is changed. For example, the assignment of a different aircraft type affects the cost function which lead to an indirect change in the flight profit. This profit change may be either increasing or decreasing which needs more investigation in the future.

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Appendix A

Newsvendor setup

Let W be the cargo compartment capacity, and V the overall volume of the cargo compartment. As aforementioned, passengers checked-in bags are allocated in a special compartment in the aircraft's belly-hold. Since the aircraft has a fixed belly-hold's capacity, and the present model considers only the cargo and extra-baggage allocated to the belly-hold, the weight constraint may be written as in equation (1):

$$w_e X_e + w_c X_c \leq W \tag{a1}$$

where w_e denotes the unit weight of the passengers' extra-baggage; X_e denotes the number of extra-baggage units; w_c is a cargo unit weight, and X_c is the number of cargo units. The volume of the rest of the belly-hold space of weight $W'$is also an important constraint, because the baggage and the cargo have different densities. Thus, as in (1), the volumetric constraint may be formulated as in equation (2):

$$v_e X_e + v_c X_c \leq V' \quad \text{(a2)}$$

where v_e and v_c are the extra-baggage unit volume and a cargo unit volume, respectively.

Considering that the chargeable weight capacity Q of the cargo compartment is assigned to the extra-baggage X_e and the cargo X_c, the airline incurs an operating cost for each unit of these two categories. Thus, the overall operational costs, O_i for carrying this extra-baggage and cargo is

$$O_i = C_e X_e + C_c X_c \quad \text{(a3)}$$

where $i = \{e,\ c\}$ is an index for extra-baggage and cargo; C_e is the corresponding extra-baggage unit cost, and C_c is the cost of each unit of cargo.

Since the forecasted market demand and the received quantity are not easy to meet, in both air cargo and extra-baggage, it is necessary to interpret the difference between the passenger RM and the air cargo RM. On the one hand, the passenger RM is a one-dimensional problem. Thus, the overbooking takes place when the number of passengers exceeds the number of seats on the aircraft (aircraft capacity) upon the flight departure, whereas the shortage is the number of empty seats on the aircraft upon the flight departure. On the other hand, the cargo RM problem is multi-dimensional, (volume and weight), and therefore, the capacity of the aircraft belly-hold cannot be controlled (random between the weight and the volume). Because of this, we suppose that the overbooking and the shortage depend on the cargo demand forecasts and the quantity they offer per these forecasts. Hence, the airline is expected to incur another penalty cost in the two different cases. The first occurs if the overall expected market demand for both cargo and extra-baggage exceeds the sum of offered extra-baggage and cargo quantities. The penalty cost in this situation can be called the shortage cost S_i and may be expressed as in equation (4):

$$S_i = \begin{cases} s_i[D_i - X_i]\ ; & \sum_i D_i > \sum_i X_i \\ 0\ ; & \sum_i D_i \leq \sum_i X_i \end{cases} \quad \text{(a4)}$$

where s_i denotes the shortage cost for each unit of extra-baggage and cargo and D_i is the expected market demand for both extra-baggage and cargo. As mentioned in the literature (Petruzzi & Dada, 1999)[12], the demand can be determined as a function of price, whereby the extra-baggage and cargo demands are price and random variable functions.

$$\sum_i D_i = D(P_e, \varepsilon_e) + D(P_c, \varepsilon_c),\ \sum_i X_i = X_e + X_c \quad \text{(a5)}$$

where P_e and P_c are the extra-baggage and cargo prices respectively, and $\varepsilon_e, \varepsilon_c$ are extra-baggage and cargo random variables. It should be noted that the research uses two demand-price models (multiplicative and additive) (Petruzzi & Dada, 1999). We adopt Mills (1959)[13] additive case demand for two reasons. Firstly, the additive model is simple to conduct compared with the multiplicative one. Secondly, we need to reduce the risk of overbooking and shortages in our calculations, which exist in the additive one, which gives a riskless demand as shown in equation (6):

$$D(P_e, \varepsilon_e) = y(P_e) + \varepsilon_e,\ D(P_c, \varepsilon_c) = y(P_c) + \varepsilon_c, \quad \text{(a6)}$$

The demand as an additive function in price also satisfies the negative slope demand property and the variety of demand is independent of the price:

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[12] Petruzzi, N. C., & Dada, M. (1999). Pricing and the Newsvendor Problem: A Review with Extensions. *Operations Research*, *47*(2), 183-194. doi:10.1287/opre.47.2.183

[13] Mills, E. S. (1959). Uncertainty and Price Theory. *The Quarterly Journal of Economics*, *73*(1), 116-130. doi:10.2307/1883828

$$\partial D(P_e, \varepsilon_e) / \partial P_e < 0, \quad \partial D(P_c, \varepsilon_c) / \partial P_c < 0. \tag{a7}$$

Furthermore, $D(P_e, \varepsilon_e)$, $D(P_c, \varepsilon_c)$ are assumed to be dependent, and $f(.)$ is the probability density function of the demand random variables. Therefore, the cumulative distribution function is denoted by $F(.)$.

The second penalty cost occurs when the overall expected market demand is less than the sum of the offered cargo and extra-baggage quantities. The cost, in this case, can be referred to as the leftover cost H_i and may be represented by equation (8):

$$H_i = \begin{cases} h_i[X_i - D_i] ; & \sum_i D_i \leq \sum_i X_i , \\ 0 ; & \sum_i D_i > \sum_i X_i , \end{cases} \tag{a8}$$

where h_i is the unit leftover cost for both extra-baggage and cargo. The airline is exposed and incurs an extra-cost due to the imbalance between the market demand and the actual quantity ordered. The demand functions play an important role in supporting the concavity of the expected profit function, where it is assumed that the sum of $D(P_e, \varepsilon_e)$, and $D(P_c, \varepsilon_c)$ should be equal to the belly-space capacity Q to keep the linear relation between the air cargo and extra-baggage, as shown in equation (9):

$$D(P_e, \varepsilon_e) + D(P_c, \varepsilon_c) = Q \tag{a9}$$

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