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Theoretical Formulation and Demand Parameters Optimization for a Proposed Extra-Baggage Service

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Abstract **–** At present, over 3000 airlines across the globe compete with one another in order to attract passengers and cargo forwarders by offering competitive prices. In recent years, airlines have encountered two major problems: the fluctuation in the freight industry and the cargo capacity imbalance on different routes. Further, as anticipated by the International Air Transport Association (IATA), the use of wide-body aircraft will increase to accommodate the increase in passengers. This will lead to an underutilized aircraft belly hold on some routes; a change which dramatically complicates the estimation of aircraft space utilization and pricing strategies. To compensate for this unfilled space, airlines are encouraged to offer more space for passengers' extra-baggage with a new pricing policy, besides the prepaid baggage allowance. Accordingly, we have formulated a newsvendor based price model to set a new pricing policy for the new service. The model compares the expected profit from traditional cargo allocation with the expected profit of combining cargo and extra-baggage. As the demand is a function of price, the function coefficients values are important factors in computing the extra-baggage price within acceptable ranges. In this manner, we adopted the Taguchi approach to design suitable demand function coefficients. It is concluded that the slope of cargo demand function is the most effective factor in calculating the extra-baggage prices.

Keywords**:** Air Cargo, Revenue Management, Newsvendor, Pricing, Taguchi Approach.

1. Introduction

In 2016, Apple released 72-78 million iPhone 7 devices, which were assembled in different Chinese cities such as Shanghai, Shenzhen, and Zhengzhou. By the end of the year, the phones were shipped to more than 100 destinations, generally by air. The choice of air transportation rather than other modes of delivery – for example, sea transportation – is due to the value of time. For instance, it takes at least 22 days to move a shipment from any of these iPhone assembly points to the UK by sea whilst air cargo takes only between 15 to 20 hours [1]. Similarly, fashion retailers and producers of various other products make efforts to distribute their newly designed products to the market as quickly as possible so as to meet the needs of and trends in the market in different seasons. Besides the issue of time, manufacturers are concerned about the issue of safety, noting that transportation over long distances is safer and more secure by air than sea transportation[2].

The aforementioned situation motivated us to search deeply into the airline industry, especially in the freight sector, and the problems encountered. By the end of 2016, over 35%, in terms of value, of the world's freight movement was transported by aircraft and in the next 20 years, air cargo traffic is expected to grow by 4.2% annually [3]. This rapid growth in air cargo has motivated many airlines to combine cargo with passenger services, thereby moving from passenger carriers to combination (Cargo-Passenger) carriers. Consequently, they upgrade their fleet by purchasing freighters, widebody and combi-aircrafts. All these aircrafts are used to carry freight in aircraft belly hold the in addition to regular passenger. Nearly 40% of these carriers' revenue is derived from cargo operations. In 2015, there was only 1.9 per cent growth in cargo demand, which was low compared to 4.9 per cent in 2014. This decline occurred due to the slow movement in world trade and the economy[3]. On the other hand, passenger traffic is expected to double by 2035 according to the International Air Transport

Association forecasts[4]. This growth in the passenger cargo sector leads to congestion problems because of the limited airport capacities. Thereby it became crucial to investigate whether airport capacity will be able to handle the upsurge in passengers and freight. In this context, Evans and Schäfer [5] developed a prediction model to identify the airlines' adaption processes to the growing passenger demand. The model has been simulated into a system-wide scale and has been applied at Chicago O'Hare International. The simulation has been adopted in the Nash best-response game between different players of the competing airlines. The simulation showed that the airlines are able to control the constrained capacity and network in such way as to maximize revenue but with some delays. It can be concluded that the airlines can adjust their network with small delays to avoid any recess in their market share. Therefore, the use of wide-body aircraft is recommended to accommodate the wide expectations in passenger numbers. However, this may increase the probability of underutilized belly-holds on many routes. So, it can be an innovative idea to take advantage of this massive increase in its number of passengers. Adding a new extra-baggage service to the current airlines services is proposed to solve this problem and to increase the airlines' revenue. In this service, a passenger is allowed to enjoy booking more space with new price for his/her belongings. The advantage of this service can be described in two ways (i) simplicity and ease; against the backdrop that the relationship between two companies (i.e. airlines and cargo forwarders) is usually complicated as it involves many negotiations, bids and auctions, but the new service avoids all these by offering space at a certain price to any passenger (ii) passenger confidence; after activating this service, a passenger who wants to transport his/her belongings will simply book an additional space on the flight and will be confident that his/her belongings will arrive on the same flight.

Currently, airlines provide limited baggage allowance for different classes. Some passengers exceed these limits by a large margin, so, they either pay a penalty for each excessive unit weight, incurring more cost, or send their residual bags through a logistics company. The airline can eliminate the need for a logistics company by allowing more space for these passengers and charging them suitable fees. It should be possible for airlines to provide more baggage space for passengers in the aircraft belly-hold. However, in combination airlines, pricing for excessive baggage presents a dilemma since the capacity allocation between cargo, extra-baggage, and regular prepaid bags become more complicated. Any excessive baggage orders will increase the operational cost [6]. Many studies have been conducted to study the impact of separating of airlines services in airfare decision making; checked bags is one of the ancillary services which is considered in these studies. For instance, Garrow, et al. [7] studied the US airlines' trend to segregate their air fare into different revenue resources and ancillary services. They found that checked baggage is one of the most beneficial resources in the discrimination trend. However, the study focused only on low cost carriers which is not sufficient for a global approach. Vinod and Moore [8] also reviewed the airlines' branding strategy and impact of their ancillary service unbundling. Here, the airlines segment their market into different flight classes and they provide services at different prices for different passengers. i.e. excessive baggage is unbundled as an ancillary service with varied prices.

As far as we know, very few studies have been conducted on passengers baggage issues only, Wong, et al. [9] assigned baggage limits to each passenger to save enough space for cargo in the aircraft belly-hold, but we wonder if this research still in line with the vast use of wide-body aircraft with idle spaces in their belly-hold. Wong's research was directed to combination airlines, and, his model was concerned with managing revenue by combining both passengers and freight. Accordingly, the combination of cargo and passenger operations makes the functions of the airlines more complicated. Some of these duties are represented by the flight routing, scheduling and revenue management operations such as pricing and forecasting and controlling of overbooking [10-15].

In this paper, we propose a theoretical formulation of pricing for the extra-baggage service. As already mentioned, the service can be added to the current airline services in order to enhance the airlines' competitiveness. We adopt Taguchi's approach in order to determine the suitable demand functions coefficients, which are necessary in optimizing the extra-baggage price and quantity when combined with cargo service, which in turn optimizing the airline profit.

The rest of this paper is organized as follows: Section 2 encompasses the formulation of the proposed newsvendor based price model to deal with the extra-baggage and cargo combinations. Section 3 we discussed the Taguchi analysis in order to design the suitable demand coefficients in four different levels schemes. Section 4 contains the conclusions.

2. Model Formulation

In this section, the multiple variable demand based price newsvendor model (MDPNV) is conducted to set the extra-baggage prices. For interpretation, let a wide-body aircraft with lower deck capacity Q be consigned to a single segment flight. In this flight, the airline allocates passengers in the aircraft upper deck and check-in bags, cargo and passengers' extra-baggage in the aircraft lower deck. Regardless of the passenger seat assignment, the aircraft lower deck has capacity limits. Assuming that the checked-in bags occupy a fixed space in the aircraft lower deck, the rest of this capacity can be $'$. This remaining capacity is constrained in two dimensions, weight W, and volume V. Equation (1) shows that the sum of cargo and extra baggage weight and volume must be less than or equal to the aircraft weight and volume respectively.

$$w_e X_e + w_c X_c \leq W, \qquad v_e X_e + v_c X_c \leq V \tag{1}$$

where w_e, v_e denote the unit weight and volume of passengers' extra-baggage, respectively. While w_c, v_c are the cargo unit weight and volume, respectively. The amount of ordered cargo and the number of extra-baggage ordered by passengers are represented by X_c, X_e.

Carrying X_c, and X_e amounts of cargo and extra-baggage, costs the airlines operational expenses O_i. Equation (2) describes the overall expenses,

$$O_i = C_e X_e + C_c X_c \tag{2}$$

where $i = \{e,\ c\}$ is an index for the extra-baggage and cargo; C_e is the corresponding extra-baggage unit cost, and C_c is the cost of each unit of cargo. The operational cost is not only the expected cost that the airline may incur, but also penalty costs that may be paid due to the uncertain demand in both cargo and extra-baggage. Penalty costs have a direct relation with the market demand, so the airline experiences two different penalty costs. A shortage penalty cost is exposed when the overall market demand for both cargo and extra-baggage exceeds the overall quantities; this may happen when the number of no shows is larger than the number of overbookings, or when the amount of reserved space is less than the forecasted market demand. On the other hand, leftover cost is experienced when the overall market demand is less than the overall quantities; also, this problem is encountered when the overbooked quantities exceed the number of no shows. Equation (3) expresses the penalty costs PC.

$$PC = \begin{cases} s_i[D_i - X_i]\,; & \sum_i D_i > \sum_i X_i \\ h_i[X_i - D_i]\,; & \sum_i D_i \leq \sum_i X_i\,, \end{cases} \tag{3}$$

where s_i denotes the shortage cost for each unit of extra-baggage and cargo, D_i is the market demand for both extra-baggage and cargo; and h_i is the unit leftover cost for both extra-baggage and cargo. Petruzzi and Dada [16] proposed that the demand can be determined as a function of price, whereby the extra-baggage and cargo demands are price and random variable functions.

$$\textstyle\sum_i D_i = D(P_c, \epsilon_c) + D(P_e, \epsilon_e), \ \sum_i X_i = X_c + X_e \tag{4}$$

where P_c and P_e denote the unit cargo price and the unit extra-baggage price respectively and ϵ_c, ϵ_e stand for cargo and extra-baggage random variables. The demand function can be derived in two forms, namely the additive form and the multiplicative form [16]. Riskless prices are obtained through applying the additive form [17], therefore, we adopt the additive form to formulate the combined extra-baggage and cargo service, see equation (5):

$$D(P_e, \epsilon_e) = y(P_e) + \epsilon_e, \ D(P_c, \epsilon_c) = y(P_c) + \epsilon_c \tag{5}$$

Each demand function is an additive case that should satisfy the negative slope demand property and the variety of the demand is independent of the price;

$$\partial D(P_c, \epsilon_c) / \partial P_c < 0, \ \partial D(P_e, \epsilon_e) / \partial P_e < 0 \ . \tag{6}$$

Moreover, the model assumes that the extra-baggage demand integrates with the cargo demand to fulfil the aircraft capacity Q. This assumption is necessary to maintain linear relation between the extra-baggage and the cargo, and retain profit function concavity;

$$D(P_e, \epsilon_e) + D(P_c, \epsilon_c) = Q' \tag{7}$$

In the aspect of considering the airline expected profit through the multi-variable newsvendor model (MNM), the model encompasses the integration of cargo and extra-baggage; thus, the flight profit is the difference between the overall sold quantities, and the incurred costs of these quantities beside the penalty costs which differ according to the relation between the forecasted market demand and the actual carried quantities. Equation (8) expresses the profit function for different quantity-demand cases;

$$\Pi(X_i, P_i) = \begin{cases} \sum_i (P_i D_i(P_i, \epsilon_i) - O_i - h_i[X_i - D_i]) , & if \sum_i D_i \leq \sum_i X_i \\ \sum_i (P_i X_i - O_i - s_i[D_i - X_i]) , & if \sum_i D_i > \sum_i X_i \end{cases} \tag{8}$$

In terms of market demand based price, Lau and Lau [18] derived a demand function in a linear regression model as a function of prices. This model matches our need to retain the newsvendor concavity, and equation (9, 10) shows the demand functions of both extra-baggage and cargo;

$$D(P_e, \epsilon_e) = a_1 - b_1 P_e + \epsilon_e \ , (a_1 > 0, b_1 > 0) \tag{9}$$

and,

$$D(P_c, \epsilon_c) = a_2 - b_2 P_c + \epsilon_c \ , (a_2 > 0, b_2 > 0) \tag{10}$$

The random variables $\epsilon_e,\ \epsilon_c$ are defined in the ranges $[A_1, B_1]$, $[A_2, B_2]$ respectively, and $A_1 > -a_1,\ A_2 > -a_2$ is a condition to maintain the positive demand of both extra-baggage and cargo for the range of prices P_c, P_e; 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.

The expected extra-baggage price can be calculated as a function of the cargo price and the overall quantities of cargo and extra-baggage, by substituting equations (5), (9), and (10) into equation (7), as shown by equation (11).

$$E(P_e) = E\left[(a_1 - b_1 P_c + \epsilon_c + a_2 + \epsilon_c - Q') \Big/ b_1 \right] \tag{11}$$

The demand random variable can be represented by the probability density function $f(.)$ and cumulative distribution $F(.)$ therefore the overall expected profit in terms of extra-baggage prices can be expressed as in equation (12);

$$
\begin{aligned}
\mathrm{E}\,[\Pi(X_i, P_e)] = {} & P_e[a_1 - b_1P_e + \varepsilon_e]\int_{A_1}^{X_e} f(\varepsilon_e)d\varepsilon_e \; - c_eX_e - h_e[X_e \\
& - (a_1 - b_1P_e + \varepsilon_e)]\int_{A_1}^{X_e} f(\varepsilon_e)d\varepsilon_e \; + P_eX_e\int_{X_e}^{B_1} f(\varepsilon_e)d\varepsilon_e \\
& - s_e[(a_1 - b_1P_e + \varepsilon_e) - X_e]\int_{X_e}^{B_1} f(\varepsilon_e)d\varepsilon_e \\
& + \left[\left[{(a_1 - b_1P_e + \mathrm{\varepsilon_e} + a_2 + \mathrm{\varepsilon_c} - Q)}\big/{b_2}\right][Q - (a_1 - b_1P_e + \mathrm{\varepsilon_e} \right. \\
& \left. + \varepsilon_e)]\right]\int_{A_2}^{X_c} f(\varepsilon_c)d\varepsilon_c \; - c_cX_c \\
& - h_c\big[X_c - \big(Q' - (a_1 - b_1P_e + \mathrm{\varepsilon_e} + \varepsilon_e)\big)\big]\int_{A_2}^{X_c} f(\varepsilon_c)d\varepsilon_c \\
& + \left({(a_1 - b_1P_e + \mathrm{\varepsilon_e} + a_2 + \mathrm{\varepsilon_c} - Q')}\big/{b_2}\right)X_c\int_{X_c}^{B_2} f(\varepsilon_c)d\varepsilon_c \\
& - s_c[(Q' - (a_1 - b_1P_e + \mathrm{\varepsilon_e} + \mathrm{\varepsilon_e} + \varepsilon_e)) - X_c]\int_{X_e}^{B_1} f(\varepsilon_e)d\varepsilon_e
\end{aligned} \tag{12}
$$

The maximum profit for distinct extra-baggage and cargo quantities can be obtained by taking the partial derivative of the expected profit function with respect to the extra-baggage price. Therefore, the optimum extra-baggage price can be obtained by equating this derivative to zero.

In order to obtain the maximum flight profit from equation (12), we should study the different factors which may have a direct or indirect effect on this profit. The direct factors which affect the profit are the different quantities of cargo and extra-baggage, their prices and demands. Because the demand is formulated as a function of price as in equations (9,10), a_1, b_1, a_2 and $, b_2$ are indirect factors which may affect the profit value. In this regard, the next section discusses the suitable values of these four factors to obtain a high flight profit.

3. Taguchi Analysis and Parameters Design

In this section, we adopt Taguchi's approach in order to determine suitable demand function coefficients a_1, b_1, a_2 and $, b_2$. These parameters are necessary to optimize the extra-baggage price and quantity, when combined with cargo service. As shown in section two, cargo and extra-baggage demand function coefficients are involved in the flight expected profit, so the objective of the experiment is to set suitable prices for the extra-baggage, therefore the demands possess nominal ranges not too high that lead to overbooking, and not too low that lead to shortages.

In this experiment, the four coefficients a_1, b_1, a_2 and $, b_2$ are identified as control parameters. Table 1, shows the different parameters and levels used to perform the Taguchi experiment. In this manner, an L_{16} orthogonal array is adopted to carry out the experimental design which is applied to equation (11). The cargo market price is assumed to be US$2.5/kg, and the aircraft residual capacity Q'=32000 kg, and random variables are represented by two normal distributions which are represented by $\mu_e = \mu_c = 2000, \sigma_e = \sigma_c = 500$. Since the objective is to obtain extra-baggage prices which are balanced with the current cargo market, the signal-to-noise ratio for "nominal is best" is also determined for each level. Fig. 1 summarizes the results of the different effects of the four demand function coefficients

Table 1: Factors and levels of extra-baggage prices.

Controllable Factors	**Levels**			
a_1	15000	16000	17000	18000
b_1	200	400	600	800
a_2	14000	15000	16000	17000
b_2	200	400	600	800

The coefficient selection can be determined from Fig. 1. These coefficients settings are best for balanced extra-baggage price values, neither a high nor low extra-baggage price.

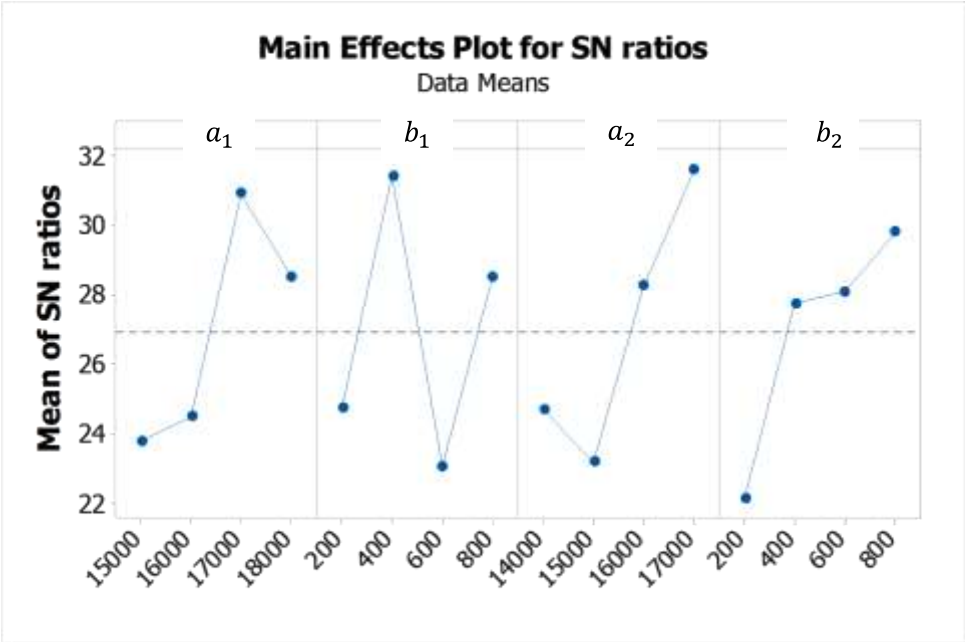

Fig. 1: The effect of demand functions coefficients on extra-baggage prices.

In the aspect of selecting the optimum coefficient levels, and based on full data, the best factor levels can be extracted from Fig. 1, as; $a_1 = 17000$, $b_1 = 400$, $a_2 = 17000$, and $b_2 = 800$. On the other hand, Table 2 shows the different extra-baggage prices in the four studied levels; the delta value in this table shows the ranks of each factor on changing the extra-baggage price. As observed, b_2 coefficient is the most effective factor in extra-baggage price calculations. This factor represents the cargo demand function slope, which also, represents cargo price elasticity, which mean that the cargo demand affects strongly the extra-baggage prices.

Table 2: Response table for means.

Level	a_1	b_1	a_2	b_2
1	2.518	7.143	2.732	13.816
2	6.975	9.288	5.285	6.887
3	6.943	7.017	9.543	4.582
4	12.271	5.260	11.147	3.422
Delta	9.752	4.028	8.415	10.395
Rank	2	4	3	1

4. Conclusions

This research proposes an extra-baggage service for combination airlines, and suggests that airlines should offer more prepaid space to their passengers. This service is intended 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 space when they have additional bags. To achieve the aim of the study, we adopt the newsvendor model to set the extra-baggage prices combined with cargo prices. The model is derived for both extra-baggage and cargo demand as a function of price. Because the demand in our model is function of price, it was necessary to design the coefficients which link the price to the demand in order to obtain balanced extra-baggage prices relative to cargo prices. The Taguchi experiment is adopted to optimise these coefficients, and the results show that cargo price elasticity highly affects the extra-baggage prices, and therefore, significantly contributes to flight profit.

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