

# Revenue Management Model for Integration of Air Cargo and Passenger with Overbooking Consideration

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**Abstract.** Revenue management is related to demand management policies to estimate and classify the various requests of pricing and capacity control. This study will develop airline revenue management model integrates passenger with air cargo that takes into account on two dimensions, namely cargo weight and volume based on the control of air cargo space. In this case, we specifically discuss the expected revenue function on dynamic programming model to maximize the expected revenue from the policies of accept or reject the booking requests between passengers and air cargo by the same airline. Moreover, in this proposed model, we also deal with the aspect of the overbooking problems. Overbooking is one of the ways in which the airlines to reduce the cost of spoilage due to cancellation or no-show. However, if the overbooking is applied in excess, it will also lead to offload costs which will reduce the airline company's revenue. This overbooking limits need to be set optimally in order to maximize revenue for the airline. Overbooking in this study is overbooking of passenger. To implement the model, we develop a dynamic programming algorithm for a set of expected revenues. We conduct some numerical experiments to show the behavior of this model.

**Keywords:** *Airline Revenue Management, Air Cargo Revenue Management, Overbooking, Cancellations, No-Shows*

## 1. INTRODUCTION

The airline industry commonly offer different prices to maximize revenues and usually referred to Revenue Management (RM). RM is often an important concern since its application used to anticipate demand uncertainty problems in the future due to excess inventory may not be stored and used in the next period, while a seats dan cargo space capacity offered always fixed and the fixed costs is high but marginal costs is low. Airline has the characteristics of perishable products, namely products which do not have residual value if it passes a certain period. That means, airlines will lost the opportunity revenue if the tickets were not sold until the flight depart. Luo Li and Ji- Hua (2007)

explains an airlines who implementing revenue management increase their revenue from 2% to 8%.

RM in the airline has two types: (i) air passenger RM and (ii) air cargo RM. Passenger RM discusses the problem of seat capacity control which about the decision to accept or deny a booking request for a particular fare during the booking period. The earliest work of air passenger RM can be traced to Beckmann (1958), Thompson (1961) dan Coughlan (1999) which develops overbooking capacity allocation in the single flight with a different fare classes and uses static random variables. Karaesman dan Van Ryzin (2004) describe a model for a single flight with some fare classes and developing capacity allocation models by calculating the limit of booking request to estimates the expected revenue

from demand. Lee and Hersh (1993) generalized single seat booking to batch booking and the request probability based on poisson arrival process to represent the demand pattern.

Previous research which addresses the existence condition of overbooking can be found in Beckmann (1958), Thompson (1961) and Coughlan (1999) which develops capacity allocation and overbooking for the single flight with static random variable of booking request. Subramanian et al. (1999) take into account of overbooking, cancellation, no-show customer and considered the penalty due to overbooking. Overbooking is a policy to sell tickets exceeding the seat capacity. This policy has a risk and could potentially harm for the airline when the number of passengers show-up upon departure is exceeds of seat capacity because the airline must provide certain compensation of overbooking penalty.

In the air passenger RM literature, some papers discussing dynamic seat allocation models for a single flight. Lee and Hersh (1993) and Subramanian, et al (1999) discussing discrete-time booking period. Feng and Xiao (2001) discussing continuous-time booking model. Luo Li and Ji-hua (2007) developed a model under competition using continuous time.

The other source of significant airline operations for revenue are air cargo. Heinitz (2013) and Huang and Lu (2015) explains an air freight services or air cargo are important to supply chain of global trade. Based on Yamaguchi (2008) inform about the largest two economies in the world, U.S. and Japan, more than 30% of internationally traded merchandise using air transportation. The air cargo industry grew 5.9% annually over the next two decades (Boeing, 2010). The characteristics of air cargo RM is different from passenger RM in many areas. Huang and Lu (2015) explain the fundamental difference is the nature of the product. For the passenger RM, seat are the product in terms of the demand related by the customer and seat capacity.

However, air cargo product are control over the sales of their limited cargo space. Cargo consume multi dimensional capacity, i.e. weight and volume are two such dimensions (Amaruchkul, 2007). They formulate weight and volume of shipments are stochastic and developed several heuristics and bounds by decomposing the problem into one-dimensional sub-problem for weight and volume. The similar single-leg problem is proposed by Huang and Chang (2010) that developed a heuristic to estimates the expected revenue from both weight and volume by sampling a limited number of point in the state space. Han et al. (2010) developed a bid-price control policy based on a mixed integer programming (IP) model. Hoffmann (2013a) recently developed an efficient heuristic that exploits the structure of monotone switching curves to reduce the computational load. Zhuang et al. (2012) proposed a general model and two heuristics that consistently outperform heuristics ignoring consumption uncertainty.

Air cargo RM is specifically discussed by several researchers. Kasilingam (1997), Bilings et al. (2003), Slager and Kapteijns (2004), Becker and Dill (2007), Amaruchkul et al. (2007), Becker and Kasilingam (2008), Becker and Wald

(2010), and Kasilingam (2011) provided the background to air cargo RM and the complexities of the product which cargo space is so much more complicated. Luo, et al (2009) creates two dimensional model (weight and volume) for overbooking issue with the aim of minimizing cost of spoilage and offloading. Haidar dan Cakanyildirim (2011) continues the research of Luo et al. (2009) With the aim for maximizing profit.

However, none of previous paper discuss dynamic programming on airline revenue management models integrates passenger with air cargo that takes into account on two dimensions, namely cargo weight and volume based on the control of air cargo space. In this model, we present a markov decision process of the free sale passenger and air-cargo booking process for a single flight with the fare classes of both passenger and air-cargo. we specifically discuss the expected revenue function to maximize the expected revenue from the policies of accept or reject the booking requests between passengers and air cargo by the same airline. Moreover, in this proposed model, we also deal with the aspect of the overbooking problems on the air passenger RM.

The remainder of this paper is organized as follows. Section 2 provides the model description to propose the model. Section 3 explore the dynamic programming model to illustrate the integration of passenger and air-cargo RM problem. The numerical experiment is described in section 4. Finally, summarizes and conclusions are drawn in section 5.

## 2. MODEL DESCRIPTION

In this study, we discuss seat and cargo allocation policy model for revenue management problem on single flights in the same airline. This study focuses in the dynamic single-leg revenue management problem on integration of passenger and air cargo with overbooking consideration. The feature of overbooking, cancellation and no-show is incorporated in the problem formulation for only passenger problem. The goal of this problem maximize total revenue from both passenger and air cargo. We develop a dynamic programming model on the same airline to optimize seat allocation of passenger considering overbooking as practiced by Subramanian et al. (1999) and integration of air cargo revenue management considering two-dimension of weight and volume as practiced by Huang and Chang (2010).

## 3. MODEL FORMULATION

In this section, we introduce in dynamic programming model for integration of passenger and air cargo on the same airline to compute the maximum expected revenue and determine the optimal policy. There are seat capacity is denoted by  $C$ . Each air passenger and air cargo contained  $m$  fare class and expressed by  $i$  where  $i = 1, 2, \dots, m$ .  $r_i$  denoted as rate of type  $i$  on passenger and  $R_i$  is rate of class  $i$  on cargo. Generally  $r_1 > r_2 > r_3 > \dots > r_m$  dan  $R_1 > R_2 > R_3 > \dots > R_m$ . The highest price class called high fare while the lower price is low fare. There are  $N$  decision periods or stages, number in reverse chronological order,  $n=N, N-1, \dots, 1$ ,

0, with stage  $N$  corresponding to the opening of the flight for reservation either air passenger or air cargo and stage 0 corresponding to its departure.

This research develop overbooking only on air passenger cases with corresponding penalties determined by an overbooking penalty function. At each stage, we assume that only one of the following events occurs: (1) an arrival customer of air passenger. The probability of each type is 0.5 and they request for a seat in fare class  $r_i$ ; (2) an arrival customer of air cargo and they request for cargo with weight and volume in fare class  $R_i$ ; (3) a cancellation by a customer of air passenger that currently holding a reservation. In this model, cancellation and no-shows occur at class independent rates, which allow us to use a one dimensional state variable. Booking requests in each fare class for event (1) and (2) according to time-dependent process. Based on the number of seat and capacity cargo already booked, we must decide whether to accept or reject each request. In addition, passenger who have already booked may cancel at any time on the  $n$  period. At this time, the passenger is refund an amount for class dependent. The passengers can also be no-shows at the time of departure and the passengers are not refunded anything.

Let  $P_{in}$  denote the probability of a request for a seat (air passenger) in fare class  $i$  in period  $n$ . And  $K_{in}$  denote the probability of a request for air cargo in the fare class  $i$  in period  $n$ . The probability of a cancellation is denoted by  $q_n(x)$  that  $x$  is the number of reserved seat on air passenger. So, we have the total probability of each stage from the all event that can occur e.x. request seat, request cargo or cancellation is:

$$\sum_{i=1}^m (P_{in} + K_{in}) + q_n(x) + P_{0n} + K_{0n} = 1$$

For all  $x$  and  $n \geq 1$

Where  $P_{0n}$  and  $K_{0n}$  represent the probability of no booking request. This model considering of overbooking as denoted by  $B$ , that means the additional number of seat offered on the passenger to response to their cancellation and no-shows. So the additional constraint,  $x \leq C + B$ .

As a function of the state  $x$  in period  $n$ ,  $U_n(x)$  denote the maximal expected revenue of operating the air passenger system over period  $n$  to 0. While losses due to no-show passenger was denoted by  $H_n(x)$ , is the total loss of revenue over period  $n$  to 0 because of cancellation and no-show.

$$U_n(x) = P_{0n}U_{n-1}(x) + \sum_{i=1}^m P_{in} \max\{r_i + U_{n-1}(x + 1) - [H_{n-1}(x + 1) - H_{n-1}(x)], U_{n-1}(x)\}$$

$$H_n(x) = \sum_{i=1}^m P_{in}H_{n-1}(x) + q_n(x)(Q + H_{n-1}(x - 1))$$

Let denote  $Y(x)$  as the passenger who show-up when the stage 0. This means  $x - Y(x)$  is no-show passenger. We have  $\beta$  denote the probability of no-show passenger and will occur only at the time of departure. However, because this model start with no seat booked at stage  $N$  and at most one customer arrive and accepted at most one request at each stage it follow at stage  $n$ ,  $x \leq N - n$ . It means that the number of reserved seat is less than the stage take place. Because each passenger have a probability of  $(1 - \beta)$  to show-up when the time of departure, then  $Y(x)$  can be expressed by binomial distribution  $(x, 1 - \beta)$ . If  $Y(x) = C + B$  it would appear overbooking penalty and denote by  $\pi_i$ . Let  $E$  is the total expected revenue of the passenger, so we have

$$U_0(x) = E - \pi_i(Y(x) - C)$$

At the stage  $n = 0$ , the possibility of other loss of revenue that may occur is the penalty of no-show passenger and denoted by  $d$ .

$$H_0(x) = (\beta \cdot x \cdot d)$$

According to Huang and Chang (2010), they formulate a multi-dimensional dynamic model for the cargo space control problem which weight and volume of various types of shipments are stochastic and calculated concurrently. The weight and volume of shipment type follows a distribution, which can be represented by a random variable. Let  $z_n(v, w)$ , be a maximum expected revenue based on the accumulated average volume  $v$  and the accumulated average weight  $w$  at period  $n$  and determine the optimal policy as equation below

$$z_n(v, w) = \sum_{i=1}^m K_{in} \max\{R_i + z_{n-1}(v + \bar{v}_i, w + \bar{w}_i), z_{n-1}(v, w) + K_{0n}z_n(v, w)\}$$

Let  $\bar{v}_i$  as the average volume of type  $i$  and  $v$  as the accumulated average volume of the accepted bookings. The average weight of types  $i$  is denoted by  $w_i$  and  $w$  as the accumulated average weight of the accepted bookings. This equation will stop when  $(v + \bar{v}_i) \geq v_k$  or  $(w + \bar{w}_i) \geq w_k$  that means if the accumulated volume of the accepted booking plus the occurring customer with volume of type  $i$  is more than the capacity of volume in the airline  $v_k$  then this customer will rejected as well as the weight constraint.

Focusses in this paper is develop the dynamic single-leg revenue management problem on integration of air cargo and passenger with overbooking consideration. The feature of overbooking, cancellation and no-show is incorporated in the problem formulation for only passenger problem, so the equation of both categories is:

$$V_n(x, v, w) = V_{n-1}(x, v, w) + U_n(x) + z_n(v, w)$$

$$\begin{aligned}
 V_n(x, v, w) = & V_{n-1}(x, v, w) \\
 & + \left[ P_{0n} U_{n-1}(x) \right. \\
 & + \left. \sum_{i=1}^m P_{in} \max\{r_i + U_{n-1}(x + 1) \right. \\
 & \left. - [H_{n-1}(x + 1) - H_{n-1}(x)], U_{n-1}(x)\} \right] \\
 & + \left[ \sum_{i=1}^m K_{in} \max\{R_i \right. \\
 & + z_{n-1}(v + \bar{v}_i, w + \bar{w}_i), z_{n-1}(v, w)\} \right. \\
 & \left. + K_{0n} z_n(v, w) \right]
 \end{aligned}$$

Where  $V_n(x, v, w)$  is the sum of total expected revenue for passenger airline with overbooking, cancellation, and no-shows consideration and the total expected revenue of air cargo airline with two-dimension of volume and weight.

#### 4. NUMERICAL EXPERIMENT

A numerical experiment was designed to evaluate the proposed model and calculating in every stage and state during the period. Some of the settings of the test problems were based on Amaruchkul et al. (2007) and Huang and Chang (2010). The optimal output at stage  $n$  will be an input on the next stage  $n - 1$ . It is assumed that there were 60 decision periods within the entire booking process of passenger and air cargo. The airline seat capacity is set by  $C = 20$  seat available and the overbooking seat is  $B = 5$  seat. We assume the overbooking limit at least 10 seats for the booking request of fare class 1. The request probability for fare classes of passenger and air cargo are shown in table 1.

**Table 1:** Request probabilities for fare classes of passenger and air cargo

Decision period	1-20	21-40	41-60
Passenger			
Rate class 1	0,3	0,25	0,15
Rate class 2	0,2	0,25	0,35
No booking request	0,5	0,5	0,5
Air Cargo			
Rate class 1	0,125	0,125	0,05
Rate class 2	0,175	0,125	0,15
Rate class 3	0,2	0,25	0,3
No booking request	0,5	0,5	0,5

The probability of no booking request of passenger is the probability of booking request in air cargo at fare class  $i$ , and vice versa for air cargo probabilities. Based on Huang and Chang (2010), there are nine cargo dimension categories of cargo shipments with varying weight and volume distributions. In this paper, we conduct three from nine categories because we use airline for passenger. The three cargo dimension categories are shown in the table 2.

**Table 2:** Mean of weight and volume distribution for cargo categories

Cargo Dimension Category	1	2	3
Average weight	80	160	400
Average volume	60	120	300

The fare classes of air cargo and passenger are shown in the table 3. The price rate of the air cargo will be used to calculate the charge of cargo in accordance with their average weight and volume.

**Table 3:** Fare classes of air cargo and passenger

Decision period	Price	Penalty/ Cancellation
Passenger		
Rate class 1	200	150
Rate class 2	150	75
Air Cargo		
Rate class 1	3	3
Rate class 2	2	1,4
Rate class 3	1	0,5

The capacity of cargo on this airline was set as shown in table 4. We set the maximum capacity each fare classes to define each cargo customer.

**Table 4:** maximum capacity of air cargo in fare classes  $i$

Capacity	Weight	Volume
Fare Class 1	3000	1000
Fare Class 2	2100	700
Fare Class 3	1500	500

In this model, we conducted two numerical experiments. The experiment 1 we provide to test the behaviour of the model when the policy open all fare classes during the period.

**Table 5:** Example result of experiment 1

Event	Passenger		Kargo		Decision	
	Passenger / Cargo	request	Class	Class		Type of cargo
60	0	-	-	1	2	accept
59	0	-	-	2	2	accept
58	0	-	-	3	1	accept
57	1	1	1	-	-	accept
56	1	1	2	-	-	accept
55	0	-	-	1	1	accept
54	0	-	-	3	3	reject
53	0	-	-	2	3	reject
52	0	-	-	2	3	reject
51	0	-	-	3	3	reject
50	0	-	-	2	2	accept
49	1	1	1	-	-	accept
48	0	-	-	1	1	accept
47	1	1	2	-	-	accept
46	0	-	-	3	2	reject
45	0	-	-	2	3	reject
44	0	-	-	1	2	accept

Table 5 is illustrate the experiment result of experiment 1, that the stage start at 60 and finish in stage 0. This means stage 0 is the departure time. In the stage 53, probability that occur is air cargo with fare class 2 and type 3. The decision in this stage is rejected the request because the remain capacity of weight and volume in fare class 2 is not enough to comply

type 3 of the request. the simulation results of this experiment, there are 4 seat that have not been reserved. Moreover, the capacity of air cargo in the fare class 1 still leaves 1960 of weight and 220 of volume. The total expected revenue achieved from this experiment is \$ 6.440.

In the numerical experiment 2, we provide to test the behaviour of the model with open the lowest fare classes until the limits run out, then open a fare class that more expensive. The example of running simulation can be seen in this table bellow.

**Table 6:** Example result of experiment 2

Stage	Passenger / Cargo	Passenger		Kargo		Decision
		request	Class	Class	Type of cargo	
60	0	-	-	1	2	reject
59	0	-	-	2	2	reject
58	0	-	-	3	1	accept
57	1	1	1	-	-	accept
56	1	1	2	-	-	accept
55	0	-	-	1	1	reject
54	0	-	-	3	3	accept
53	0	-	-	2	3	reject
52	0	-	-	2	3	reject
51	0	-	-	3	3	reject
50	0	-	-	2	2	reject
49	1	1	1	-	-	accept
48	0	-	-	1	1	reject
47	1	1	2	-	-	accept
46	0	-	-	3	2	accept
45	0	-	-	2	3	reject
44	0	-	-	1	2	reject

Table 6 is illustrate the experiment result of experiment 2. In the stage 60, probability that occur is air cargo with fare class 1 and type 2. The decision in this stage is rejected the request because the policy to accept the lowest fare classes while the probability of highest fare class was occur (class 1). The simulation results of this experiment, there are 4 seat that have not been reserved. Same with the experiment 1 but , the capacity of air cargo in the fare class 1 still leaves 2280 of weight and 460 of volume, and also the second fare class still have 1380 of weight and 160 of volume that unbooked. The total expected revenue achieved from experiment 2 is \$ 4.800.

## 5. CONCLUSIONS

We have developed a dynamic seat and cargo allocation model for the same airline considering Overbooking, Cancellations, and No-Shows on the passenger. We have developed a dynamic programming to optimize ticket fares of both cargo and passenger simultaneously and dynamically over the selling horizon. We also have conducted several numerical experiments to examine the proposed model behavior in terms of total expected revenue.

In this study, refund for customers who cancel their reservation is different price when they wanted to buy for an airline ticket. From the numerical experiment, we have compare that open all fare classes in the both passenger dan air cargo booking request is more profitable than open fare

classes step by step from lowest fare class. The policy of open the fare classes is very take effect when decide to open all fare classes and step by step open from lowest price. Future research may consider the relevance of refund with the price paid by the customer when he reserved the ticket as well as considering the overbooking of air cargo and extra baggage of the passenger.

## ACKNOWLEDGMENT

The authors would like to express their thanks to the referees for their valuable suggestions and comments. This work is supported by Institute for Research and Community Services- Universitas Internasional Semen Indonesia (UISI).

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