A Multi-Period Dynamic Optimization Approach for Revenue and Capacity Management in Air Cargo Transportation

by

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ABSTRACT

Air cargo as an industry dealing in across the border shipping of commodities has experienced much success as well as remarkable growth in the recent past, thanks to the evolutionary developments the sector has enjoyed over the past few years. Technically speaking, there would be no profit maximisation by companies offering such services if there was not a perfect technique of selecting shipments to transport. The secret behind ensuring that an air cargo company gets the most out of its services, in terms of profits earned, is a function of its ability to identify the correct shipments to accept as well as the capacity required to spare for each type of cargo amongst those shipped.

This study performs a careful analysis in this sector with the aim establishing effective results. The key factors this thesis covers are the design of two different models and their corresponding practical applications.The incoming booking requests for every given time unit are characterised by their capacities, which are in the form of weight and volume and a third parameter of profit rate. These parameters have the sole objective of distributing the available requests in such a manner that maximum profit is earned at the end of the booking period.

It is then upon the carriers to make a decision as to whether they should accept or reject the incoming booking requests based on the cargo's capacity, weight, volume and nature. The bid-price mechanism was employed such that whenever the income generated by a given request exceeds its opportunity cost, as indicated by the profit rate, then the request is automatically approved. This procedure is simulated using a dynamic environment. The programme monitors the entire process and summarises the results at the end of every trading season. At this point, the programme selects the most profitable booking requests in terms of weight, volume and profit rate. These selected parameters are then used to calculate the new bid-price, which is then adopted for the subsequent trading

period. This way, the subsequent year is characterised by more profitable requests than the previous season. Simulations will be developed to bring an understanding of how such models can be used to achieve the intended objectives.

First, the model deals with generating a bid-price mechanism for a single-leg flight such that whenever the income generated by a given request exceeds its opportunity cost as indicated by the profit rate, then the request is automatically approved. Mixed-Integer Non-Linear Programming (MINLP) is developed to calculate dynamic bid-prices that are adjustable at each time unit and solved in a dynamic environment. Bid-prices are calculated closer to departure time when a booking is assumed to be more urgent and charged higher than regularly bookings. However, when a flight is close to its departure time, certain bookings may be accepted and charged regularly to prevent the flight taking off under occupied. Results are compared with static bid-prices, which are calculated once over the decision horizon and results obtained from applying FCFS policy.

Second, we suggested adapting a fare-class approach, which is a common technique in passenger revenue management. The customers' requests can only be accepted if there is space in the particular fare class to which they wish to apply. The problem could be approached using the nonlinear programming model (MINLP) hence the revenue function is first linearised before proceeding. The results are compared with the FCFS policy and a booking limit model by introducing dynamic threshold values, which is achieved by limiting the capacity available for shipments in each fare class.

Challenges associated with these models will also be discussed to create a clear justification as to why certain methods are recommended and others discouraged. The thesis will end by testing the performance of each of these models. This way, the effectiveness becomes testable and hence the models can be graded.

ÖZET

Küreselleşme ile birlikte karmaşıklaşan tedarik zincirleri taşımacılık sektörünü dünya ekonomisi için oldukça önemli hale getirmiştir. Malların sınırlar arası nakliyesi ile uğraşan bir endüstri olan havayolu taşımacılığı yakın geçmişte sektörün son birkaç yıldır gördüğü evrimsel gelişmeler sayesinde bir çok başarının yanı sıra kayda değer bir büyüme yaşamıştır. Bu süreç sonucunda nakliye şirketleri stoklanamayan kaynaklardan elde edilen karları maksimize etmek için tüketici davranışlarını anlama süreci olarak tanımlanabilen kapasite ve gelir yönetimi sorunu ile karşı karşıya kalmıştır. Kapasite yönetimine göre satılacak kapasite sabittir ve ulaşım gerçekleşmeden önce işlenmesi gerekmektedir; bu nedenle taşıyıcı karar vereceği dönemde gelen rezervasyon talebini belli bir gelir karşılığında kabul edebilir ve ya daha sonraki dönemlerde gelme ihtimali olan daha karlı bir talebi bekleyebilir. Eğer nakliyeci bu kararı doğru olarak verebilirse, en karlı taleplere hizmet edebilir ve bu sayede sınırlı kapasite ile daha fazla kar elde edebilir. Bu nedenle ulaşım için talep arttıkça, etkin kapasite ve fiyatlandırma yönetimleri çok önemli hale gelmektedir.

Bu çalışmada ulaşım sektörünün kapasite tahsisi ve fiyatlandırma sorunu dinamik programlama modelinde gelir fonksiyonuna dayalı olarak ele alınmaktadır. Karar dönemi kısa süreli zaman birimleri ayrılır ve her zaman birimi içinde belirli sayıda rezervasyon talebi nakliyeciye ulaşır. Nakliyeci gelen rezervasyon talebini kabul edip etmeyeceğine kalan kargo kapasitesine ve talebin ağırlık, hacim ve türüne göre karar vermek zorundadır Teklif-fiyat kontrol politikası her satış sezonunun başında en uygun fiyatlar hesaplanarak kısa vadeli kapasite kontrolünü incelemek amacıyla uygulanmıştır.

Öncelikli olarak tek-bacaklı uçuşlar için teklif-fiyat mekanizması üreten bir model üzerine çalışılmıştır. Bu kapsamda geliştirilen model, gelen bir talebin kabul edildiği durumda elde edilecek olan kar oranı teklif-fiyat politikası ile belirlenmiş olan fırsat

maaliyetini aşarsa gelen talebin otomatik olarak kabul edilmesi üzerine kurulmuştur. Bu bağlamda, her zaman biriminde farklı olarak ayarlanabilen dinamik alış-fiyatlarını hesaplamak için Karışık Tamsayılı Doğrusal Olmayan Programlama geliştirilerek dinamik bir ortamda çözülmüştür. Kalkış saatine yakın zamanda ulaşan rezervasyonların daha acil olduğu varsayılır ve bu tip rezervasyonlar için teklif-fiyatları diğer rezervasyonlardan daha yüksek tahsil edilerek hesaplanır. Ancak uçağın kalkış saatine yakın zamanda ulaşan bazı rezervasyonların ücretlendirilmesi, uçağın gereğinden az kapasite ile kalkmasını önlemek amacıyla normal rezervasyon teklif-fiyatlarıyla yapılabilir. Bu modelden elde edilen sonuçlar, tüm karar periyodu boyunca bir kez hesaplanan statik teklif-fiyatları ve önce gelen önce sunulur politikası uygulanarak elde edilen sonuçlar ile kararlılık açısından karşılaştırılmıştır.

İkinci model olarak yolcu gelir yönetiminde yaygın bir teknik olan ücret-sınıf yaklaşımı uygulandı. Bu tekniğe göre sadece ilgili ücret sınıfında yer varsa bu sınıf için talepte bulunan yolcuların rezervasyonları kabul edilmektedir. Bu problem doğrusal olmayan programlama ile modellenebilmektedir bu nedenle öncelikle kar fonksiyonunun doğrusallaştırılması gerekmektedir. Bu modelden elde edilen sonuçlar önce gelen önce sunulur politikası uygulanarak elde edilen sonuçlarla ve her ücret sınıfından gelen taleplerin dinamik eşik değerleri kullanarak kabul edilecek olan kapasitelerini sınırlayan bir rezervasyon modeli uygulanarak elde edilen sonuçlarla karlılık açısından karşılaştırılmıştır.

Bu çalışmada ayrıca diğer yöntemlerle ilişkili uygulama zorlukları, neden belirli yöntemlerin önerilip diğerlerinin ele alınmadığına net bir gerekçe oluşturması açısından anlatılmıştır. Bu çalışma önerilen modellerin her birinin performans testini de ele almaktadır; bu şekilde yöntemlerin etkinliği test edilebilir ve dolayısıyla modeller tasnif edilebilir hale getirilebilir.

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NOMENCLATURE

AWB	Air Way Bill
GDP	Gross Domestic Product
V	Volume of a shipment (m^3)
W	Weight of a shipment (kg)
D	Inverse density of shipment (m^3/kg)
ϖ	Chargeable weight of a shipment
δ	Weight/volume ratio of a shipment
ρ	Total revenue anticipated from that particular shipment
r	The shipments unit price (price of a single kilogramme of the shipment)
λ	Poisson process arrival rate
EMSR	Expected Marginal Seat Revenue
IATA	International Air Transport Association
FCFS	First Come First Served
MDP	Markov Decision Process
μ	Mean of the sampling distribution
σ^2	Variance of the sampling distribution
MINLP	Mixed-Integer Non-Linear Programming
MIP	Mixed-Integer Linear Programming
θ_s	IATA's standard inverse density
U	Uniform distribution.
β	Threshold capacity limit for fare classes
ESDN	European Sustainable Development Network

Parameters

Cw	Weight capacity of airplane
Cv	Volume capacity of airplane
W_i	Weight of the i^{th} shipment
V_i	Volume of the i^{th} shipment
w_i	Realisation of the weight of the i^{th} shipment
v_i	The realisation of the volume of the i^{th} shipment
d_{wt}	Weight of an individual demand arrived at t^{th} time period
d_{vt}	Volume of an individual demand arrived at t^{th} time period
R_i	Per unit (per kilogramme) revenue of the i^{th} shipment whose realization is r_i
ρ_i	The total revenue generated by the i^{th} shipment
$\bar{\omega}_j$	Chargeable weight of demand j
T	Decision time horizon
t	Decision time period
d_{wjt}^i	The weight of the j^{th} demand in the i^{th} scenario arrived at t^{th} time period
d_{vjt}^i	The volume of the j^{th} demand in the i^{th} scenario arrived at t^{th} time period
p_{dit}^i	The profit rate of the j^{th} demand in the i^{th} scenario arrived at t^{th} time period
$capaw_{i,t}$	Available weight capacity in i^{th} scenario arrived at t^{th} time period
$capav_{i,t}$	Available volume capacity in i^{th} scenario arrived at t^{th} time period
w_{jt}^i	Chargeable weight of j^{th} demand in the i^{th} scenario arrived at t^{th} time period
ε,s	Very small constants
M_1, M_2, M_3,M_4	Large constants.
wL_l	Lower limit for chargeable weight bracket l
wU_l	Upper limit for chargeable weight bracket l
$conv_b$	Volume of container b

Variables

x_i	Binary variable for acceptance/rejection decision of booking request i .
hw	Minimum bid price with respect to a unit of weight.
h_v	Minimum bid price with respect to a unit of volume.
$conv_b$	Volume of container b.
con_b	Binary variable become 1 when container b is used and 0 otherwise.
$y_{i,b}$	Binary variable become 1 if demand i packed into container b.
x_{jt}^i	Binary variable 1 whenever the j^{th} demand in the i^{th} scenario arrived at t^{th} . time is approved and 0 if the booking request is rejected.
w_{jt}^i	The binary variable becomes 1 whenever $d_{wjt}^i \geq d_{vjt}^i/\theta_s$ and 0 otherwise.
X_{jt}^i, y_{jt}^i Z_{jt}^i	Binary variables for acception and rejection constraints for the j^{th} demand in the i^{th} scenario arrived at t^{th} .
$k_{i,l}$	Binary variable becomes 1 if bracket l for class i is selected and 0 otherwise.
r_b	Scalar variable determines how many numbers of container b should use for packing selected demands arrived.
h_{wt}	The bid-price corresponding to weight capacity at t^{th} period.
h_{vt}	The bid-price corresponding to volume capacity at t^{th} period.
$cuw_{i,t}$	Total used weight capacity in i^{th} scenario arrived at t^{th} period.
$cuv_{i,t}$	Total used volume capacity in i^{th} scenario arrived at t^{th} period.

Chapter 1

INTRODUCTION

The transport sector is considered one of the largest economic benefactors in the world. This sector is experiencing rapid growth with the rapid expansion of the global market. The transport sector is divided into three main categories, which include water transport, rail transport and air transport. Research indicates that the transport sector commands up to five per cent of total employment opportunities in European Union countries, which translates into a total of seven per cent of the region's Gross Domestic Product [1]. Although regional transportation is dominated by railway and waterway transport, air transport is still popular as far as freight transportation is concerned. Air transport has enjoyed a dramatic annual growth, which is approximated to be between six to seven per cent, and research indicates this rate is expected to increase to an average of 6.4 per cent within the next twenty years [2]. The anticipated growth brings a new challenge in the form of effective managerial requirements, which are needed to ensure that necessary standards are sustained within the sector.

The passenger sector normally gives customers the freedom of making their booking requests either directly or through the use of middlemen. When the second booking technique is used, customers are advised on how to make effective choices through the comparison of different prices and terms of service. As for the second case, there are a few parties that must be paid, which literally suggests this method as a less expensive undertaking than booking through intermediaries. For the cargo sector, on the other hand, the booking process is dominated by the use of intermediaries and most of the time, there is no direct contact between the shipper and the carrier. There is, therefore, a lack of honesty as the shippers are never sure of the differences that obviously exist

between the rates they pay and those paid by their shipper competitors. This problem can be solved with the use of integrators. The entire chain of cargo supply is owned by a single body such that all processes and payments made can be monitored by the shippers. It is a much more efficient, time-saving and transparent method that can be a suitable substitute to known crude methods.

Each carrier is usually characterised by both cargo and passenger capacity, where each type of capacity is distinct from the other in terms of service conditions and the corresponding encounters. Such capacity systems also have their own strengths and weaknesses. Most customers like to settle for Belly capacity, due to the fact that they are very efficient and choosing them means that customers are less likely to be inconvenienced by booking cancellations. It is, however, important to note that most cargo cannot be included in the passengers' carrying flights, due to the fact that some of them have capacity and safety requirements that a passengers' section cannot effectively provide.

The entire air cargo business in made up of three basic parties in the form of the shipping company, people dealing with the forwarding process and those who carry the cargo. For the case of the transport sector dealing with exported cargo, there are two more parties who are the destination forwarders and the consignees. The companies or individual customers who intend to use the aircrafts to transport their cargo to their desired destinations are known as the shippers. The term 'carriers,' on the other hand, refers to airline owners who approve booking requests with the intention of allowing shippers to use their planes' capacity to transport cargo. They are the airline service providers. 'Forwarders' describes the middlemen who connect the shippers and carriers. Forwarders are very important in the air cargo supply chain in that they are responsible for creating an understanding between the first two parties through activities such as price negotiation and handling the paper work involved in the air transport sector.

Once an agreement is reached between the two parties, the goods are shipped in accordance with the agreed upon terms. The export and import customs are settled before the destination forwarders are used, to ensure the cargos are safely delivered to the intended recipients.

'Revenue management' refers to the process of maximising the income of the income earned by a given firm in a given selling season. Airline firms are able to earn high incomes in a given season, thanks to their management teams who carry out detailed analyses on the consumers, enabling them to predict the consumers' behaviour and demands. This way, the firm is capable of achieving one of the most important aspects of business, which is timely sale of the right products to the desired customers for the right price and at the right time. The prices at which the goods are sold are, therefore, the customers' own valuation of the products. Due to the fact that the air transport industry is experiencing rapid growth, the concept of revenue management has become an unavoidable requirement in this sector. It works toward ensuring there is sufficient capacity for selling to customers with high revenues, at the same time, making sure the available capacity is fully utilised.

In the recent past, the concept of e-freight has been introduced into the air transport sector. This concept is characterised by mechanisation of operations as well as encouraging the introduction of highly integrated information technology in the day-to-day activities in the sector. Digitalised booking has been introduced which has, in turn, led to the need for more complicated revenue management systems. Introduction of digital systems is intended to boost the efficiency of the cargo pricing process, achieve highly secure recordkeeping and security systems as well as modernise the process of booking through the introduction of online booking methods.

This concept of revenue management is of much importance to airline firms in several ways that lead to profit maximisation and reduction, if not complete eradication of

losses that may arise due to poor revenue management practises. First, the amount of profit that each passenger seat can produce is maximised. Most useful assets of the airline are well-managed such that the future demand of passengers can be predicted and appropriate actions taken to counteract such changes. Research indicates that proper management of airline assets has raised corresponding revenue earned by up to eight per cent [3].

The value of each passenger seat is also maximised when revenue management is properly employed. Aircrafts that usually have empty seats, whether they are fully booked or not, can benefit from revenue management, which enables them to acquire optimum sale of seats. Revenue management enables air transport providers with the knowledge of how to maximize the revenue from each seat during each flight made by their aircraft by properly allocating capacity. This leads to a massive boost in the productivity of the firms as well as earning command of a desirable portion of the market.

Revenue management is also highly compatible with the basic operations taking place in the market. Other factors into which revenue management can easily fit include pricing mechanism, design of fleet schedules and other key factors in this sector. This system accelerates the upgrade of both small and large airlines. It also makes firms capable of generating revenue to a higher extent, as compared to other systems.

The application of revenue management has become a popular research topic as well as the most developmental weapon considered by any airline company in the world. Revenue management aims primarily to ensure that companies obtain the desired income in exchange for the commodities they transport on behalf of their customers. This concept has made cargo air transportation a very marketable business as well as a very popular and important economic activity. Most investors initially feared venturing into such business activities for fear of operating under low incomes. However, with the introduction and successful employment of revenue management, the field has become attractive to most investors who are always assured of positive returns for their funds and capital they input

into the business. With the effective use of revenue management, it has become logical to shippers that they do not have to exploit their customers to maximise income. They have also learnt ways of reducing the costs incurred by their customers through the process of integrating all parties involved in the air cargo supply chain under one unit, ownership and supervision. This has reduced the number of salaries involved and hence relieved customers of unnecessary payments. As a result of this, the air cargo industry has gained remarkable marketability, followed by substantial growth.

The performance of the firm in previous selling seasons is carefully reviewed and analysed. Such observations are used in planning for the future or in setting the organisation's goals. Where there has never been complete success in the past, the knowledge can be used to correct organisation's weak areas. This way, the decision making process is more informed and has effective consequences. The revenue patterns of the organisations can be planned and finalised using observations made from forecasting the passengers' demands and the income trends experienced by the firm in past selling seasons. It is also possible to predict and approximate utilised capacity of any flight. The providers can actually predict the expected passenger population, the expected cargo alongside their dimensions and hence the amount of fuel required for any flight. This way, the cargo capacity for a single flight can be easily deduced. This is of significant use to the carriers, since it helps in planning the financial requirements and the corresponding revenue expectations; two important parameters in calculating the anticipated profits by the organisation.

Once revenue management skills have been used in predicting the flight parameters, it becomes even simpler to forecast the capacity allotted for a flight and the demand curves for certain goods at specific stations. This concept is then used to create the different allotments to different stations depending on the values as per the predictions. Revenue management also assists in managing the capacity through dynamic consideration of

standby shipments, queues and cargo to be pre-carried from flights that are yet to take effect. A single leg flight, as used in the airline business, refers to a flight in which the passengers or cargo under transit will be granted an hour of free time in a single day made of twenty-four hours. Multiple leg flights, on the other hand, refer to a situation where a flight is completed in more than one session, and most of the time, such a flight is characterised by multiple stoppages before the items on transit finally arrive at the desired destinations. The items on transit usually have multiple hours of free time, which actually neither coincides with the other's nor comes at the same time of the day.

With revenue management, booking requests can be effectively evaluated with respect to the calculated bid-price. The requests are then accepted or rejected depending on whether they meet the bid-price requirements or not, the main driving factor being profit maximisation and loss minimisation. The consequence of this is that pricing mechanism is achieved through the projection of the consequences of the newly set rates.

With regard to revenue management, bid-price policy is widely employed. The term 'bid prices' refers to a price used to determine whether the incoming customer booking requests will be accepted or rejected. It is the threshold price below which the carrier rejects incoming books and above which the requests are approved.

The aims of determining a perfect capacity optimisation is to solve problems such as underutilisation of the aircraft's total capacity. For instance, at times, a plane is fully booked but some space is left unoccupied due to the fact that certain shipments were preferred to others with regard to fare classes. In the case of there being unoccupied passenger seats in a large number of flights, it is important to refabricate the aircraft such that the number of passenger seats is reduced and the cargo capacity increased by the same factor that the passenger seats have been reduced with. Such a step can, however, be taken only after monitoring and asserting that there the changes will yield positive results. This evaluation process can be achieved by means of computer simulation. However, the scope

of this thesis does not deal with such types of adjustments. The coverage assumes the passenger seats have already sold out and the capacity allotted by long-term agreements have also been considered. It, therefore, focuses on the remaining capacity, which is basically left for cargo transportation in particular.

However, when the plane is fully booked and there are empty allotments in the cargo section while the passenger seats are fully occupied, it is important to create a simulation to monitor what would be the impact of reducing the capacity of the cargo section by a given factor and then increasing the capacity of the passenger section by the same factor. If positive results are obtained, then refabricating the plane in accordance with the given specifications can always lead to revenue maximisation. Some planes are always created in such a way that different classes are charged differently. At times, certain classes are characterised by more occupants than others, leading to a situation where a given class is fully occupied while others have numerous unoccupied seats.

In such a case, it is important not to make classes having equal number of seats. The passenger distribution pattern should be monitored over a long period of time to obtain the most consistent pattern. This pattern can then be used to determine the most effective distribution of the number of spaces in each section. A computer simulation will be used to monitor the behaviour of the revenue with different combinations of the number of spaces in each class. This way, it is easier to end up with the most profitable combination for such an aircraft. This technique is in essence a revenue management mechanism as well as capacity management, since it explains how to control the way the plane's capacity can be manipulated at different sections for the purpose of profit maximisation.

The purpose of this research is to address the problem that arises due to capacity allocation and pricing techniques, based on the dynamic programming model characterised with uncertainties in demand.

Chapter 2 provides a theoretical background on pricing techniques in the transportation sector, especially for the air cargo business under certain circumstances and gives a comprehensive overview of researches conducted on revenue management principle.

The problem statement and the developed models are explained in Chapter 3.

Results obtained by running the programme are tabulated with an illustrative example in Chapter 4. Additionally, benchmarking problems are solved in this chapter with discussion of results.

Finally, Chapter 5 includes the conclusion and summary of results and the arguments related to these results with future recommendations.

Chapter 2

LITERATURE REVIEW

2.1 Pricing

The term ‘pricing’, as defined by Geman [4], is the process by which a production company or any other profit-making organisation evaluates its goods or products. Price determination entails the setting of the company’s expected income in exchange for its commodities, which may be in the form of goods and services. The process of pricing is dependent upon several factors, most of which are factors of production and of course the need to make reasonable profits by the company in question. Such factors include the cost of production, the difference in the product grades as well as the product’s quality and quantity. Pricing is a fundamental requirement as far as microeconomics is concerned, as it forms part of the 4Ps (product, promotion, place and price), which are required in the marketing process. Of all these factors, it can be seen that the only one of them directly responsible for direct income generation is the price, even though the other factors are as important as it is [5].

Munier and Ivanenko [6] describe the process of pricing as a process that can be achieved either manually or automatically with the aim of assigning valuation to orders that involve buying or selling of commodities, in this case, goods and services. They argue that deterministic factors of pricing include factors such as product quantity, fixed capital employed in the production process, resources applied in product promotion, product quality and the prices of such a commodity already prevailing in the market. Manual pricing involves carrying out calculations that lead to approximate valuation of the company’s products. When conducting this process, the company’s factors of production,

and any other expenses incurred throughout the process of producing the product, are usually taken into account. The results are then used to manually approximate the price of the product in question.

Automatic pricing, on the other hand, is achieved by the use of computer programmes to create simulated prototypes of market behaviour. Several adjustments are made until the most appropriate price is determined. According to Liang and Bliault [7], the consumers' desires to consume a particular commodity can only are useful to the producers, if and only if it is accompanied by the ability to spend on such commodities. Pricing can be approached using different techniques, which results in different types of pricing methods. Some of these pricing techniques are discussed below.

The first method of pricing technique is referred to as 'line pricing'. Here, the number of prices for the whole of products being offered is limited. For example, a vendor may decide that all the commodities he or she is offering can be grouped into two price categories, say, you can purchase a product whose price is either P1 or P2. The commodities do not have to be identical for them to be priced like this. The bottom line is that they have been confirmed to be of similar value. Schaeffer [8], however, thinks that despite this pricing technique being preferable due to its simplicity; it is inflexible and can lead to complications, especially during inflations.

Another pricing technique is the premium pricing technique, which involves setting the prices of commodities just before the high end of the anticipated price range. Customers who are sensitive to price status usually become easily attracted by this pricing technique. It is referred to as 'prestigious pricing', due to the fact that the high valuation is normally taken as an indication that the product is of high quality, luxurious, worthy and operates without any flaws.

Some producers tag prices on their commodities depending on the current demand of such commodities; a technique referred to as 'demand-based pricing'. It is accompanied

by practises such as discriminating the pricing process and other related irregular price determination procedures.

Fontanills and Gentile [9] describe this method as only helpful on the goods which demand keeps fluctuating with time such that producers can create price hikes during peak seasons when the demand for such commodities rise. They can then reduce prices when the demand falls, as a measure of encouraging people to increase their consumption of such goods and to prevent spoilage for non-durable goods. Finally, we have the pricing technique known as the ‘multidimensional pattern’. As defined by Burton and Holden [10], this pricing method uses several numbers to determine the price of a given commodity.

The price is not immediately tagged on the commodity but rather spread throughout different modes of payment, each of which has its own magnitude, depending on the level of risk involved alongside other factors the seller may be willing to incorporate. For example, a seller may decide that if you want to purchase his or her goods, you have to part with a small amount of money in the form of a down payment, after which you complete the remaining amounts in a given number of instalments. In one way or another, this is a hidden form of price discrimination, since whoever purchases goods on an instalment basis will pays a price totally different from another consumer who pays for the goods and purchases it on a cash basis [11].

According to research, as indicated by Phillips et al [12], this method is a good tool to psychologically interfere with the way customers understand the entire concept of commodity pricing.

2.2 Pricing with Finite Capacity

Pricing is a very fundamental concept in the sector of air transportation. The model adopted by management should be as dynamic as possible, to avoid any complications. In order to determine the charges that customers are expected to pay in exchange for air transportation services, cargoes are considered to have such dimensions such as weight, volume and charge. These three factors are used to obtain an approximation of the expected charges. The most applicable of the three parameters are weight and volume. The cost of transporting cargo can be calculated bearing in mind the deterministic parameters of the plane, which are weight and capacity. Charges related to a particular shipment are usually collected from the shipping company under consideration of whose items are to be shipped. These charges are referred to as the 'freight charges' and usually appear on the shipment's corresponding Air Way Bill (AWB). In accordance with arguments documented by Hoffman [13], when the goods to be sent are of special nature, say livestock or other forms of animals such as pets, the freight charges can only be submitted through the person in charge of the shipment. Based on the capacity and the volume of the shipment, the freight charges can be calculated by following manual procedures or using a computer programme that can be used to devise the most appropriate charges customers are bound to pay.

2.3 Pricing in Air Cargo

The fare charges corresponding to the services offered by this sector are arrived at after carrying out mathematical manipulations on the dimensional properties of the aircraft, both when loaded and/or when empty. It has also been agreed upon that the concept of price determination is important in maximising sales and obtaining an equilibrium state where profits are maximised and the risks minimised [14]. Below is a step-by-step

description of how price determination can be achieved through manual mathematical manipulation of the characteristic dimensions of the aircraft and the corresponding load, which are in either in the form of passengers or cargo.

The first stage of this process deals with the determination of the predefined dimensions of the aircraft, as provided by the manufacturer. Such parameters include the total weight of the vessel when not occupied, loaded or fuelled. This weight is normally referred to as the 'standard weight' of the aircraft and is usually predefined by the manufacturer of the plane. It is followed by determination of the maximum weight the aircraft can withstand without being structurally destroyed, a parameter termed as 'maximum gross weight'. This encompasses the total weight of the plane when occupied by passengers and loaded to full capacity. The other factors that should be keenly noted, according to Cheng-Jui Lu [15], are the aircraft's maximum take-off weight and the corresponding maximum comfortable weight during landing. These two weights are the maximum endurable weight of the aircraft when it takes off and the maximum possible weight of the aircraft when it lands such that the landing gear is not destroyed, respectively.

The capacity of the aircraft's fuel tank should be determined, as this parameter will be very useful in calculating the fuel capacity of the vessel to know the amount of weight that fuelling it will add to the total weight. The next step is the calculation of the weight contributed by the fuel. The weight of the fuel added is used instead of the fuel tank capacity, due to the fact that the tank may itself not be fully filled. The volume of the loaded fuel together with the fuel density can be used to calculate the mass and hence the weight of the fuel. Alternatively, US gallon or British imperial conversion constants may be used to carry out direct conversion without having to go through the complex calculations.

The maximum payload is then calculated by subtracting the aircraft's standard weight together with the weight of the loaded fuel from either its total weight when loaded

or the maximum weight at take-off. However, it is always recommended that the take-off weight be used instead of the gross weight for the reason that the former is usually less than the latter [16].

This payload is then shared among the passengers and the total number of cargo items in the aircraft. The members of the aircraft crew are normally incorporated into the passenger count and considered as passengers, preferably, the actual weights should be used in this calculation, as documented by Findlay and Warren [17]. Again, American gallon or British imperial conversion constants may be used for accurate and direct conversion, which takes into account even tiny details such as the weights of the passengers' clothing. The total weight of the passengers and the crew members can then be subtracted from the calculated payload to obtain the maximum weight available for cargo and other non-human materials under transit. Havel [18] insists that the aircraft's actual volume should not be in one way or another incorporated into the process of determining cargo capacity, as this will be limited to the period before the vessel leaves the surface.

Finally, the craft's maximum landing weight is considered. It is also important to note that the maximum endurable weight at take-off is larger than the landing weight. This is because by the time the aircraft is landing, it is logical to argue that it shall have consumed most of the fuel that was filled in the fuel tank and hence the weight shall have reduced by a given factor proportional to the weight of the fuel consumed [19] . This process can also be achieved by simply using a dynamic programming model. Here, a pre-written programme is fed with different parameters and followed by numerous numerical adjustments, which results in a favourable equilibrium from where the most favourable price is derived.

It is of great importance to consider the nature of the cargo, which price life span is known to be short before they go bad. These types of cargo usually require proper handling techniques, close supervision and care as well as appropriate storage while on transit. It is

expected that these products be priced differently from others, since the aircraft must be installed with special equipment for handling and storing such goods. The additional requirements may imply that the airline company incurs extra costs in handling and storing these products while being transported, a fact which leads to the need for such items to be priced different from those that require less handling, probably a little higher as compared to those that are just placed in the capacity space and transported.

2.4 Air Cargo Business

The airline industry has evolved into more of a more sophisticated sector with revenue management playing a key role in facilitating this type of evolutionary development. The viability of this industry is strongly dependent on the concept of revenue management. This concept is an emerging issue and has gained much popularity throughout the industry. It is not a profitable business practise to aim primarily at minimising the cost of production and operation. It is required that any business organisation make reasonable profits; failure to so would result in the entire business losing meaning. Businesspersons who venture into this industry find themselves with several hardships associated with the business, ranging from difficulties encountered in management to the increasing competitions they face day-by-day, coupled with the weakening economy.

The air cargo business as an industry has undergone developmental changes and a sequence of evolutionary stages. As a result, scholars such as Hellermann [20] have been able to categorise this business into three main categories or business models. These models include full-service carrying models, low cost carrying models and charter airlines. A full-service business model refers to that type of air cargo business where the shipment company offers a combination of passenger transportation services, cargo transportation

and courier services. Low cost services and charter airlines deduce their meanings from the names themselves.

These models have resulted from the fact that the industry has been highly deregulated and even privatised. According to Neufville and Odoni [21], deregulation, which is the removal of governmental regulations that control business management and price determination, is favourable for the purpose of the development of this business. The first regions to ever experience this scenario were in the United States and were characterised by the elimination of governmental control on fare and territorial coverage. This enabled aircrafts within the European Union to follow any routes within the territories under the European Union without any strict regulations [22]. Graham et Al [23] argue that deregulation did not only eliminate unnecessary regulations but also intensified competition in the industry, resulting in a drop in the overall yield. Today, most airline companies have devised sophisticated business models that have enabled them to expand their market opportunities by minimising their cost of operations, lowering charges and making maximum possible profits. The business models have recently become so similar that differentiating them has become quite difficult. With respect to arguments proposed by Aldamari and Fagan, airlines can eradiate negative consequences of unnecessary competition by following what he called general airline strategies. These include cost leadership, differentiation and focus strategies.

This business is taken seriously in the United States, for example, where the industry constitutes up to 3,000 different companies. This industry earns the United States a noteworthy $120 billion dollars a year [24]. In this region, the business is diversified and expanded to accommodate other services such as courier services. The market is dominated by only a few of the companies. For instance Genzberger [25] observed that up to ninety per cent of the total revenue earned by the entire industry is contributed by only twelve of the 3,000 airline companies constituting the industry.

Small airlines with annual incomes of between $5 and $50 million dollars are the most abundant constituents of the airline industry in the United States. This industry is highly dependent on the country's economy.

Air freight is a short-cut to transportation of important items. Such items are those of utmost importance to the customers and include valuable goods such as gold and diamonds. Transported goods may also include those that require urgent delivery procedures. When valuable goods are transported using this method, they are believed to be safe from general risks such as unintended damages and hijacks, since airlines are less prone to hijacks as compared to land-based transportation mediums. This sector has been of great importance to other business sectors. It has solved the problem that arise when businesspersons intend to transport bulky goods or otherwise quickly. Airlines allow businesses the freedom of choosing the types of freights that best suit their requirements, and their requirements are taken care of using scientifically devised conditions or simply developed conditions using logically understandable ways. The industry is rapidly evolving and becoming heavily sophisticated. This has brought into existence a new challenge, which is the need to employ advanced technology and knowledge in management and day-to-day management practices. New developments have evolved such as online booking and the use of computer0aided programmes in managing, conducting and supervising the operations that take place. As we saw earlier in this thesis, dynamic programming models have also been successfully incorporated in the price determination procedure. This has increased the efficiency with which activities are undertaken while at the same time reducing human effort.

Shipping cargo using air transportation has, on many occasions, been criticised for being an expensive undertaking and is believed to be the major cause of price hike in items. An item manufactured in India, for example, may cost up to ten times what it costs in India, after being shipped to the United States. Businesspersons whose goods are shipped using

air transport tend to recover the money they spent in shipping the goods by increasing the final prices of such goods. This is the major contributing factor toward the fact that goods transported through airlines are unbelievably expensive. The cost of shipping items is also high due to the high cost of driving factors such as fuel, initial cost, maintenance cost, and tax rates.

With respect to the challenge discussed above, most airlines have realised the only way to reduce shipping prices such that the customers do not feel exploited and the company owners do not run their businesses at a loss, is by offering a wide variety of shipping services. This way, income generation is widely diversified and so are risks and other forms of challenges involved. This is supplemented by the establishment of large airline companies by either spending huge starting capitals or simply merging the already existing small businesses into larger ones for the purpose of enjoying economies of scale.

The continued need to transport goods rapidly, as demanded by customers across borders has made this sector very important to businesspersons. There have been remarkable developments developed in the field of marketing and commerce in general. Such developments include ecommerce in which producers can reach their customers from any part of the world and the two can conduct any business transactions through the internet [26]. For the purpose of ensuring efficiency for their buyers, producers must deliver the goods purchased by such buyers as fast as possible. This problem has been solved by the introduction of massive transportation of goods by different air cargo shipping services offered by many companies across the globe. Countries that rely heavily on air transportation of goods in most of their export and import related businesses have recorded massive income in the past years, according to research [27].

However, it is important to note that the air transport business and cargo business have become part of the world’s newest fields of development and intensive research. The usefulness of this sector to the economies of many countries of the world as well as

individual businesspersons has attracted the interest of venturing into the field with more professional approaches [13]. Most governments have incorporated the research related to this field into the systems of education in their corresponding countries to encourage more scholars into the field, as they see this as a useful step in encouraging technological and other forms of development required by the sector [28]. Effectiveness, security and any other factors that contribute to the efficient functioning of this business have been prioritised for obvious reasons. The high qualities of services offered have been used to convince customers it is worth their money. Most countries across the world respect the air transport sector, due to the massive revenue contributions that the sector offers. Through the air transport sector, most countries are able to make connections with other countries hence the development of the tourism sector.

2.5 Revenue Management Principle

The research into in the field of revenue management has intensified, especially in the passenger section, while booking requests in the cargo sector have become limited. Kasilingam [29] was the first scholar to highlight the distinctions between revenue management in the cargo sector and that in the passenger sector. He came to the realisation that it is rather complex to achieve successful revenue management with regard to the cargo department of air transport. Such complexities were further analysed by Müller-Bungart [30] who examined this in greater depths, enabling him to improvise tentative solutions and better ways of coping with them.

According to Billings [31], in his articles aimed at providing fruitful proposals in dealing with cargo revenue management complexities and designing the appropriate framework, the sudden changes that have been experienced in the cargo business has resulted from mechanisation and work automation that has emerged in this industry. Graff

[32] is in complete agreement with Billings' claim and adds that it is quite difficult for an airline transportation business that comprises both cargo and passenger transportation to achieve much of success. Mathematically, cargo revenue management can be optimised using certain algorithms that are suggested by several articles that have been written and published by several scholars. One of such algorithms is the intentional sale of more stock than the available stock to ensure no losses are incurred as a result of last minute cancellations. This revenue management technique is referred to as 'overbooking'.

Kasilingam (1997) [33] designed a special cost-effective model of conducting healthy overbooking, depending on the capacity. The very first algorithm to deal with the problem of deciding whether to approve or reject the demand for a given capacity was developed by Pak and Dekker [34], using the multidimensional 0-1 knapsack model. However, Ling Hang et al. [35] argue the problem is more of a Markovian model used in handling the problem of whether or not to approve requests. Hung suggested that if the capacity is assumed to be uncertain, then dynamic programming should be used to approach this puzzle.

As documented by Huefner [36], the concept of revenue management begun a few decades ago in merely primitive forms, which included just overbooking before developing into a more complex form that we are aware of today. The immediate stage that followed the very first form of revenue management was the subdivision of products to meet the diverse nature of customer requirements. Such sub-categories were called 'classes' and were characterised by different terms of services and different characteristic differences. Advanced computer programmes were then used to aid in the process of bid-price determination and hence decision making, with respect to whether to accept or reject booking requests. Furthermore, researching seat inventory is rather a complex procedure and therefore the researchers had to make certain assumptions to achieve the hypothetical expectations. For this case, six assumptions were made and they included (1) the

assumption that the booking process was sequential, (2) low fare booking is to be handled ahead of high fare booking, (3) the booking classes are assumed to be statistically independent, (4) the process is assumed a hundred per cent such that no-shows and late cancellations do not practically exist, (5) booking is with respect to a single flight leg and finally (6) it was assumed that there was not any batch booking. These assumptions and their relevance in deriving cargo and passenger parameters were documented by Talluri and Van Ryzin [37].

These assumptions were used by Belobaba [38] to devise a forecast on the trends expected in the seat revenue; a term he called 'Expected Marginal Seat Revenue', abbreviated as EMSR, which has since become very helpful in booking request decision making. Further developments proceeded until four other scholars successfully developed a dynamic programming model of simulating this process.

Model designs, which were mainly based on assumptions one and two, were referred to as static models and were less effective, even though they were of much logic than the initial crude models. The need to integrate dynamic programming became a necessity, which caused Lee and Hersh [39] to come to the rescue. They came up with a programming model that represented the demand trends of each fare class using the probability of booking requests, as determined by the Poisson's function of order arrivals. After expanding the sixth assumption to cover batch booking rather than just the single seat booking technique, the two scholars came to the realisation that the probability of booking request occurring was also a function of the total magnitude of overall booking. The model developed by Lee and Hersh, however, did not take into account the possibility of cancellations and no-shows. After extensive research and prototypic tests, Subramanian et al [40] devised several improvements to the programme previously developed by Lee and Hersh to incorporate cancellations and no-shows with respect to the fourth assumption. He

realised that cancellations and no-shows could actually be taken care of by the consequences that emerged due to selling more stock than there was available.

The bid-price control mechanism was then pioneered by Talluri and van Ryzin [41] to counteract the challenge of network revenue management, which actually had a weakening effect on the fifth assumption. This technique assisted in handling the problem by the use of a linear programming model such that the seat price for every flight leg was a constant. The problem could also be disintegrated into its constituent sub-problems, which implies that the network revenue management challenge was handled by considering each flight leg in the network; a process known as 'virtual nesting'. It is, however, important to note that the concept of network revenue management is a recently emerging problem in the field of revenue management and researchers are still busy carrying out research in this particular field.

Revenue management has become a clearly defined discipline in the world of economics for the reason that many service-providing companies, especially air cargo industries for the purpose of revenue maximization, have fancied its appropriateness. Such industries usually apply economic aspects such as market segment pricing alongside economic statistical analyses aimed at market expansion. In the long run, the results of these activities include market enlargement and hence the maximisation of the revenue generated per available physical booking capacity [42].

Boonekamp, et al. [43] argue that the concept of revenue management can only be productive and helpful if employed in a technically intelligent manner and that the outcomes of effective use of this principle can yield benefits such as profit increments and hence maximum revenue generation. They suggested that for an airline company to reap the fruits of revenue management, the company must be characterised by properties. These properties include the possibility of the demand for the company's services being segmented into different market segments with each segment being characterised by its

independent price; such a firm should also have a relatively fixed capacity such that it becomes too expensive or simply impractical to adjust the firm's inventory. Marginal costs due to the sale of any additional capacity to the available one are quite small, compared to the costs incurred by the offer of the service. The firm should be characterised by ability to adjust prices in accordance with the changing balance between the demand and supply with the services of the company having definitely predictable demands. Such a demand has repetitive highs and lows, which can only be approximated and not predicted with definite precision.

In light of the above-mentioned assumptions, the principle of revenue management can be divided into six steps, which include (1) segmenting the market demand and pricing the segments differently, (2) pricing in a peak/off-peak system, (3) demand prediction, (4) allocations of inventories, (5) anticipated revenue prediction and (6) employment of the principle of marginal revenue.

The first step in revenue management involves pricing the market segments. This involves the disintegration of the market into several segments with each segment being designed a particularly discriminated price. The primary objective of this practise is usually to assign relatively high prices to market segments, which demands are insensitive to price fluctuations, while charging relatively lower prices to market segments that are characterised by price-sensitive demands. The process of market segmentation and price discrimination is usually achieved through variation of the rates at which the commodities are being shipped [44].

The above-named step is then followed by pricing services offered in a peak/off-peak system; this is usually characterised by the addition of the aspect of time in the process of market segment pricing. The system is aimed at maximising both sales and revenue at different points. During the periods when demand is off the peak, the prices are lowered to encourage large-scale purchases. On the other hand, when the demand rises to

the peak, pricing is increased to ensure that maximum possible revenue is earned from sales. It is also assumed that the company's shipping services become more of necessity to the clients. In this process, the demand is controlled while income revenue is maximised [45]. The subsequent step followed is the aspect of allocating inventory corresponding to the created market segments with a main objective of maximizing the expected revenue.

The value of the expected revenue can then be approximated by obtaining the accurate numerical estimation for every unit of capacity corresponding to each of the available sale dates. The concept behind this process is the fact that the level of the available capacity on the airline and the marginal revenue resulting from the sale of any extra unit of capacity are inversely proportional (an increase in one leads to a decline in the other). This also implies that an airline company with only a single unit of capacity enjoys high probability of sales that do not require the use of discounts to lure consumers into purchasing. The consequence of this is that the first-time estimation of the expected revenue will give a relatively large figure and a slight reduction in the probability of the sale of any additional unit of capacity to a customer. At this point, the company finds itself under pressure to offer discounts to promote the extent of capacity booking. This may continue until it reaches a point where the firm is forced into offering a high capacity, such that it becomes almost improbable to achieve the sale of an additional, even if the firm wishes to literally give it away and in this case, the expected revenue tends to zero [46]. The above phenomenon is achievable by the use of a special curve known as the 'expected revenue curve'.

The final step of this process involves employing the principle of 'marginal revenue pricing', which involves the actual application of the information obtained from the expected revenue curve in real life pricing mechanisms. This data can be made use of either through the traditional way or with the bid-price method. For the first case, which is also the most employed technique in the airline industry today, capacity reservation is

sequentially incremented as far as the fare class with the highest charge rate is concerned. This is repeated until the point when the marginal revenue for the reservation of the next capacity to a customer becomes less or equal to the proceeding low rate.

Another instance involves the use of this information in a bid-price approach. In this case, the final value of marginal capacity is adopted as the least price at which booking requests can be accepted, also known as the 'bid price'. The acceptance or rejection of a booking request is then considered to be solely dependent on the determined bid price such that any rate valuated as less than the bid price is automatically rejected, while that which is higher than the bid price is accepted.

2.6 Omitted Concepts and Suggested Inclusions

The literature review has offered several ideas concerning nearly all the areas of interest as demanded by this thesis. However, there are certain points that have not been included of which inclusion could prove very helpful in increasing the efficiency and effectiveness of this industry, which it's primary objective such as any other business is the maximisation of reasonable profits while minimising risks. If the literature review was to provide a lasting solution to the problems highlighted in this thesis, then it should have included the idea of fare classes. This should have come in the form of how to allocate different capacities related to weight and volume to different fare classes such that the overall revenue generated will be maximised. Below, is a description of two concepts that can be keenly looked into if one desires to add more value to the benefits of the air transport sector.

A part of the literature covers the only static bid-price mechanism developed as MIP (Mixed Integer Linear Programming). These models ignore the time and capacity effect on prices. On the other hand, dynamic bid-price models are handled only using MDP

(Markov Decision Process). We developed a dynamic multi-period model for detecting bid-prices using a MINLP (Mixed Integer Non-linear Programming).

In addition, the services offered by airlines, especially the passengers' section are subdivided such that charges are made in accordance with categories as the fare classes. It would not be surprising to find out that a given class or group of classes is more crowded while others have several seats unoccupied. In business language, one would say this is a waste of space and hence money. My suggestion is that a given company should use the statistics of their operations over a given period to be able to declare the trends of passengers' behaviour, in terms of selecting fare classes. This should enable them to approximate the average number of passengers who occupy each fare class, the class with the highest and lowest occupants and the class most likely to experience a change in the number of passengers occupying it. Seasons such as summer, Christmas, and winter should also be used to predict demand trends for each fare class. More seats and space are then allocated to fare classes with the highest demand. This idea is important in ensuring that fare classes are fully occupied and hence generate the maximum possible income. The consequence of considering this idea is elimination of the problem of underutilisation, which arises when certain fare classes have excessive seats that are empty due to low demand for such classes.

Decision making regarding the above concept cannot be achieved by just manually trying figures. The trial and error method cannot be used to achieve the best ratios of different capacities allocated to each of the fare classes suggested above, which emphasises that computer-aided operations are unavoidable in this particular process. I suggest that the behaviour of the generated revenue when stimulated by different combinations of the fare classes should be observed using appropriate computer software, after which the final decision can be made. With the achievement of the most effective combination of

capacities to be allocated for each of the fare classes, it would be easier to maximise revenue, which is the sole objective of any business.

Chapter 3

PROBLEM STATEMENT

3.1 Introduction

The main problem addressed by this study is the design of appropriate models to handle the challenge of air cargo booking, especially for single leg flights and short time allocations. The bid-price control technique is going to be very helpful in determining the maximum endurable capacity alongside the capacity allocation with respect to a single leg flight. As we shall see later in the project, booking technique is a very important in the process of maximising the revenue earned by the business. We will focus on how to attain the perfect booking pattern such that it leads to maximum income, which is almost equal to the hypothetically anticipated figure

The second problem to be handled by the study is how to maximise capacity. It would be quite problematic making decisions concerning how to distribute the volume and weight capacity available in a single flight to attain maximum income. Many businesspersons who think literally would tend to imagine that the best way to maximise revenue generated is by increasing the volume and weight capacities of the high-revenue fare classes, while reducing the volume and weight capacities of low-revenue fare classes. This, however, is not very helpful and the only way to achieve appropriate combinations will be determined using the models to be discussed here. First, we analysed the problem by assuming a single flight with a well-known destination and with a certain capacity exists. We attempted to figure out the optimal booking process. With the second part, we carried out a fare class based approach to the cargo revenue management problem, which is a common approach in passenger revenue management. While developing the optimisation

models no-show, cancellation and overbooking concepts are omitted. The models booking on the basis of the aircraft capacity and chargeable weights for different shipments with different properties, the spot market approach will lead us into a situation where the maximum capacity and the chargeable characteristics are substituted by the capacity constraints and the bid-price control constraints.

3.2 Designing a Model for Air Cargo Booking

Designing a model for air cargo booking is a technical process that deals with creating different degrees of stimuli related to the booking technique and observing the corresponding outcomes. This process can be carried out several times until a point is reached that gives the best results. If this process was to be experimented with in real life, it would be very costly and some of the results could have effects on a company's revenue, effects that are so diverse that by the time an appropriate equilibrium is attained, the airlines may not have any resources left to adopt the production technique suggested by such a booking technique.

A computer simulation that represents the nature and behaviour of cargo bookings is a fundamental factor in the quantification of how effective is a particular revenue management system. The most appropriate and professional way of approaching the process of designing an appropriate booking technique is through the use of a model that will offer perfect returns, preferably outcomes close to the theoretically anticipated ones. The choice of model itself is another task altogether and requires that certain requirements be met first before its execution can begin.

First, one needs to devise a means of characterising the nature of the cargo with targeted bookings. Useful characteristics that are usually helpful in the design of a simulation model include volume, weight and density. The fact that density and weight are

independent variables can help us obtain this, since it is a function of the two parameters. The weight and density are first derived using the fundamental units of conversion and then the volume calculated in accordance with the relationship formula that exists amongst the three characteristics. After generating the shipments' characteristics, the obtained values are tagged on the shipments such that the corresponding prices can be easily discriminated. The generation of cargo dimensions can be approached in different ways, depending on the designer's preferences and the primary objectives of the design.

The time difference between the booking moment and the moment a flight takes off is usually a commonly considered factor. The closer to departure time a booking is the more urgent it is assumed to be and hence such late bookings are normally charged higher than the regularly cleared bookings. They are therefore of much more benefit than others in terms of income generation. However, when the flight is close to its departure time and there are several unoccupied spaces, despite having undergone a busy booking process throughout its booking period, certain bookings may be accepted and charged regularly to prevent the situation which leads to the flight taking off under-occupied.

The flexibility and reliability can also be increased by assigning demand patterns for departures and arrivals instead of concentrating on the booking technique based on specific flights. This is easier to achieve, especially after monitoring the pattern shown by flights sharing the same destination for a long time. The technique is said to be more convenient to customers whose chief interests are always to be assured of the timely arrivals of their cargo. The properties characterising shipments can be calculated and used in price determination. One way through which air cargo acceptance/approval decisions and hence booking control can be achieved is through several techniques, which include designing specific characteristics of the incoming or anticipated shipments and then using simulations to design an appropriate charging rate and a function of the shipment properties that also maximises the revenue earned. Another approach this study employs is the

determination of the design of these decisions on the basis of certain mathematically designed control.

3.2.1 Weight and Volume Modelling

Shipments whose booking requests are incoming are characterised by several properties, which are very important deterministic factors. The most fundamental of all these properties is the size of the incoming cargo shipment. The cargos with booking received requests usually differ from each other in many ways. They can be small, medium or large. The other factor that differs among the shipments is their densities. The cargo are of different natures and hence the differences in their densities. If these parameters are known, the shipments' weight and density can be modelled using their normal logarithmic distribution. Normal logarithmic distributing function always gives positive values with a fat-tailed density function, implying that the probability of the occurrence of values much greater than the average exists and is reasonable.

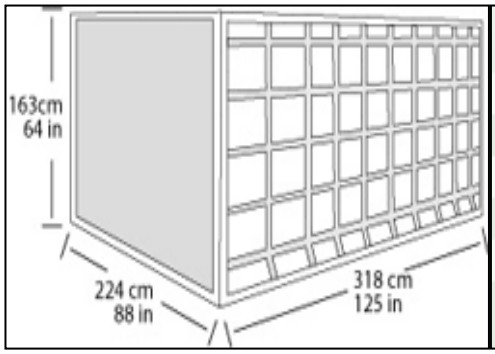
To calculate the exact values of weight and volume of the shipments, variables (V) and (W) are anonymously chosen to represent volume and weight, respectively. The two parameters are then expressed in their normal algorithmic forms. The fact that the volume of a shipment is directly proportional to its size clearly implies that these two parameters are dependent variables. There is, therefore, the need to introduce a third factor, which is the inverse density of the shipment expressed as V (m^3) divided by W (kg). This factor is mathematically expressed as r.v. D, where inverse density D (m^3/kg) is assumed to be approximately equal to log N (μD, $\sigma^2 D$), and is as independent as (W), as supported by the fact that there can be variations in the shipment's density, irrespective of the weight. The volume can hence be derived dimensionally using the expression:

$$V = D * W \tag{3.1}$$

V is approximately equal to log N ($\mu W + \mu D$, $\sigma^2 W + \sigma^2 D$) since the product of two normal logarithmic functions also has a lognormal distribution. The implication of this idea is that the volume is also a normally distributed function.

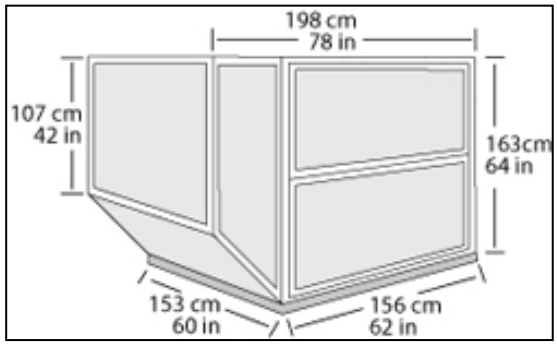
3.2.1.1 Modelling the Utilized Capacity in Airplane

The approved requests should be packed into containers before shipping, therefore, the weight and volume of the containers used should be taken into consideration, while determining the total volume occupied by the booked requests. There are different types of containers available for carrying the freight. We assumed aircrafts only accept two types of containers, AMJ and AKE, where AKE is a half-size lower deck container and AMJ is placed on the roof. In addition, they have different volume capacities and gross weights. When the demand is packed in one of these containers, it will occupy the space as much as the volume of the container itself. We assumed the weights of containers are negligible and did not affect the given total available capacity of the plane in terms of weight.



	(metric)
length	3175 mm
width	2438 mm
height	2435 mm
volume	17.4 cu m
tare weight	289 kg
max gross weight	6804 kg

Figure 3.1: Dimensions and Specifications of Main Deck (AMJ) Container



	(metric)
length	1988 mm
width	1534 mm
height	1610 mm
tare weight	> 69 kg
max gross weight	1588 kg

Figure 3.2: Dimensions and Specifications of Lower Deck (AKE) Container

3.2.2 Chargeable Weight and Revenue Modelling

Having successfully derived the expressions for volume and weight of the shipments expressing them in the form of V and W, respectively, it is very important to note that not all of the derived values of these two parameters are used in determining the corresponding charges posed on customers. There is, therefore, a need to introduce the aspect of chargeable weight. This is the specific weight that will be considered to be responsible for costing the aircraft in terms of maintenances, repairs and fuel requirements. The other weight is idle and does not in one way or another affect the operations of the airline company. It is, however, not an obvious requirement that the weight and volume discrepancies be handled by employing the chargeable weight, but it is only applied whenever the shipment has a lower inverse density than the expected weight to volume ratio, which is 1:6. Chargeable rate is a function of volume and weight and is expressed as follows:

$$\varpi = \max\left(\mathrm{dw}, \mathrm{dv}/\theta_s\right) \tag{3.2}$$

- IATA's standard inverse density, θ_s.

The term, d_v/θ_s, also known as the dimensional weight is a very important factor, as far as charging is concerned, for the reason that if the cargo's density is in excess of the dimensional weight, the density in cargo is charged on the basis of its own density, while cargos with lower densities than the dimensional density are charged in accordance with their individual weights.

The corresponding revenue models should be specific, effective and in accordance with each of the encountered booking requests. The rates at which the cargos will be charged are diverse and dependent on many factors that have been discussed. Such factors include shipment sizes, anticipated flight and services demand patterns, and the way each customer is valued by the service-providing company under consideration. The revenue expectations are calculated per kilogramme of the shipment's calculated chargeable weight. As a result, it is ensured that the recommended charges are very much dependent on the sizes of the shipments. Another important point to note here is that either the revenue generation can be randomly generated or through the disintegration of services into smaller independent units known as fare classes, in which case, the charges are independently decided upon with respect to the prevailing conditions in each of the classes under consideration.

In the case of random revenue generation, decision-making procedures involved in charging shipments adhere to the real world expectations. Shipments to be transported are charged using a justifiable price discrimination procedure, as the cargos are charged with respect to their characteristics, its individual chargeable weights. This modelling technique is usually simple, direct, understandable and realistic, which is the basic reason why it is widely applied in modelling the solutions to problems involving one-leg flights. Its derivation is achieved using the following procedure. A function r is assumed to be a random variable representing the shipments unit revenue (price of a single kilogramme of the shipment). Apart from being a random variable, r is also a continuous function whose

probability distribution function is taken to be g (r). Given that spot rate from accepting a certain type of cargo is r and the total revenue anticipated from that particular shipment is ρ with the chargeable weight being ϖ . Then the total revenue expected to be generated by such a shipment is given by the following expression:

$$\rho = r.\varpi \tag{3.3}$$

It is also worth noting that the spot rates usually vary amongst different categories of cargo, which leads to a situation where the spot rate, r, is therefore assumed to follow a discrete distribution with given as $\{r_1, r_2, r_3 \ldots r_a\}$. In addition, the spot rate, r, does not depend on either the demand weight, d_w or the demand volume d_v such that the rejection of a particular booking request is not accompanied by any negative consequences.

3.2.3 Modelling a Single Leg Booking Problem without Fare Classes

The constraints this study adopts are those used in modelling single-leg flight parameters in the spot market when ignoring the existence of fare classes. When creating a model to solve this problem, it is usually assumed there is only a single flight with a well-known destination and its capacity is constrained. This particular assumption is a justification of the fact that decision making regarding booking requests will no longer occur when the capacity becomes larger than the demand. Arrival of bookings follows the Poison Process with each arrival characterised by a randomly assigned weight, volume and the corresponding revenue. The resulting price that is derived from this procedure is known as the least acceptable. These prices are the equivalent of bid prices, as used in revenue management. Two models relevant to bid-prices exist—(1) static bid-prices, which are calculated once over the decision horizon and (2) dynamic bid-prices that are adjustable at each time unit. Because the dynamic model exhibits a bumpiness structure, we adopt a scenario-based approach to overcome the disturbance. The corresponding procedures used

in designing several aspects of the decision making and hence the decision itself are described below.

3.2.3.1 Modelling the Single-Leg Booking Problem Using Static Bid-Prices

The booking control problem can be modelled as well by first applying the Poisson's process to generate a series of booking requests. This is then followed by the generation of the realisations corresponding to volume, weight and revenue. For the purpose of revenue maximisation of the flight leg in question, an effective criterion for accepting or rejecting booking requests is then developed. This method model is referred to as the booking control problem. It is usually important to be able to measure productive revenue management in theory and the best way to do this is by means of the optimal solution. Through this method, we are able to make observations on the effectiveness of the booking process under the control of regulations set by us and compare it with the hypothetical expectations. In simple terms, this concept offers solution to the problem of knowing the booking requests that ought to have been approved considering the entire booking requests under observation.

Volume and weight are taken to have normal logarithmic distribution and the unit revenue (for each kilogramme) is assumed to be a random variable with a probability distribution function of g (r). This leads to an unavoidable scenario of R also having a normal logarithmic distribution. The following parameters are applicable.

- Poison process of arrival rates denoted by the symbol λ
- Weight capacity of airplane denoted by *Cw*
- Volume capacity of airplane denoted by *Cv*
- Weight of the i^{th} shipment denoted by W_i

- Volume of the i^{th} shipment denoted by V_i
- Realisation of the weight of the i^{th} shipment denoted by w_i
- The realisation of the volume of the i^{th} shipment denoted by v_i
- Per unit (per kilogramme) revenue of the i^{th} shipment whose realisation is r_i denoted by R_i
- The total revenue generated by the i^{th} shipment denoted by ρ_i
- Time horizon denoted by T

In conjunction with these parameters, the variables listed below are also of use in this particular process.

- Binary variable for acceptance/rejection decision of booking request i denoted by x_i
- Minimum bid price with respect to a unit of weight denoted by hw
- Minimum bid price with respect to a unit of volume denoted by h_v

We introduced a new parameter and variables to specify the available volume of airplane considering the container usage:

- Volume of container b is denoted by $conv_b$ (b=1,2)
- con_b: binary variable become 1 when container b is used and 0 otherwise
- $y_{i,b}$: binary variable become 1 if demand i packed into container b
- r_b: scalar variable determines how many numbers of container b should use for packing selected demands arrived

The mixed-integer non-linear programming model is described by the following expressions:

$$\text{Max } z = \sum_{i=1}^{n} \rho_i x_i \tag{3.4}$$

$$\text{s.t. } \sum_{i=1}^{n} w_i x_i \leq Cw \tag{3.5}$$

$$\sum_b \text{conv}_b \quad r_b \leq Cv \tag{3.6}$$

$$\text{conv}_b \quad r_b \geq \sum_{i=1}^{n} v_i \; y_{i,b} \quad \forall b \tag{3.7}$$

$$\text{con}_b \leq \sum_{i=1}^{n} \; y_{i,b} \quad \forall b \tag{3.8}$$

$$r_b \leq M1 \;\; \text{con}_b \quad \forall b \tag{3.9}$$

$$x_i \leq \sum_b y_{i,b} \quad \forall i \tag{3.10}$$

$$hw \; w_i + hv \; v_i - r_i \leq M2 \; (1 - x_i) \quad \forall i \tag{3.11}$$

$$r_i - hw \; w_i - hv \; v_i + s \leq M3 \;\; x_i \quad \forall i \tag{3.12}$$

- n is the total number of booking requests received
- M1, M2 and M3 are sufficiently large numbers
- s is a sufficiently small number

This model makes use of the multidimensional 0-1 knapsack problem, which is a very popular technique in solving much simulation problems in the field of research. The revenue management must decide whether to accept or reject a particular booking request out of a total of n requests. The decision making must be clever in nature to ensure that at the end of it, the consequences are profit maximisation and the capacity requirements are not exceeded. Equation 3.6 ensures the total occupied volume calculated from multiplying number of containers used with the corresponding volumes of these containers should not exceed the given capacity of plane cabin. Equation 3.7 stands for determining the necessary

number of containers for each type to pack each accepted order. The constraint of an accepted order should pack into a selected container is ensured with Equation 3.8. In addition, we provide by Equation 3.9 that if a container type is not selected to pack an order, then the number of containers used for this type should also be 0. Equation 3.10 ensures that each accepted order is packed into a container without division. Finally, Equations 3.11 and 3.12 indicate the bid-price control constraints.

When this problem is characterised by multidimensional parameters, it becomes quite complicated and hence the need to devise appropriate algorithms for solving it. According to the implications of the deriving equations of this model, it becomes a very helpful technique that is applicable in the attempt by airline companies to maximise profits. The model does not merely assist in making decisions, but also helps revenue management to understand the logic that lies behind the decisions it makes. One of the methods ever discovered to assist in solving this NP-hard problem is known as the "greedy algorithm". The method was discovered by Rinnooy Kan et al [42] and has been very helpful in obtaining an approximate solution to the problem. The greedy algorithm alters the sequencing of items with respect to the item's relative profit and control policies.

3.2.3.2 Modelling the Single-Leg Booking Problem Using Dynamic Bid-Prices

With respect to the scenario approach, the parameters used in decision making are the capacity and bid-price control constraints. This is because the equivalents of the chargeable capacities in this approach are the capacity constraints and the bid-price control constraints. The bid-prices are calculated at every period of time, in accordance with remaining capacity from accepted orders and remaining time to departure. The design of these two parameters is achieved by the following procedure.

Firstly, the notations used by this method to design a model for the booking problem are as follows:

- The time period between T and t is referred to as the decision period.
- T is the departure time.
- *t* is any time period along the decision process. And other notations include;
- Cumulative weight of accepted booking requests until period *t*, W_t.
- Cumulative volume of accepted booking requests until period *t*, V_t.
- Weight capacity for air cargo, c_w.
- Volume capacity for air cargo, c_v.
- Weight of an individual demand, d_{wt}.
- Volume of an individual demand, d_{vt}.
- Joint probability density function (pdf) of weight and volumes of demand, f_{wv} (d_{wt} d_{vt}).
- Constant arrival rate, λ.
- Probability mass function (pmf) of discrete variables or probability of the happening of a certain event, prob.

Consider a single flight whose weight and volume capacities are given as C_w and C_v, respectively. Supposing there is a given period of booking during which different types of demands with different weights and volumes are received by the decision-making unit at a constant rate λ. Upon receiving a booking request, the airline decision-making panel must decide on whether to accept or reject the booking request based on the nature of the demand and the prevailing profile for selling. Only one of the two options end up being taken, and whenever the panel decides to approve the booking request, there will be revenue earned by the airline company.

The entire booking period is constituted by T booking periods, which range from 0, 1, 2, 3…T. In the indexing, the first and the last periods, denoted by 0 and T are taken to represent the beginning of the booking period and the departure of the flight respectively. This model assume a very large value of T such that one time period is characterised by strictly one booking arrival. This gives rise to a situation whereby the rate λ at which requests arrive is far much less than one (λ <<1). With this condition, the arrival of a booking request in a particular

The booking period has a probability of λ and the probability of there being no demand arrival is approximated as being equal to 1- λ. Any booking request is accepted under the following conditions valid for each time unit:

$$r \max (d_{wt}, d_{vt}/\theta_s) \geq h_{wt} d_{wt} + h_{vt} d_v \quad \forall t \tag{3.13}$$

$$W_t + d_{wt} \leq c_w, V_t + d_{vt} \leq c_v \quad \forall t \tag{3.14}$$

where;

h_{wt}= weight bid price at period t.

h_{vt} = volume bid price at period t.

W_t = cumulative weight of the accepted shipments until booking period t.

V_t = cumulative volume of the accepted shipments until period t.

The term, r max (d_{wt}, d_{vt}/θ_s) from inequality 3.13 is the term that represents the revenue that is earned from the approval of such cargo. The exact value of this revenue can only be determined upon the arrival of the corresponding booking request, since only then can the exact values of volume, weight and the nature of the shipment be known. The other part of the inequality (h_{wt} d_{wt} + h_{vt} d_{vt}) is a representative of the opportunity cost of approving the booking request that corresponds to the shipment category under consideration. The opportunity cost is itself dependent on the both the bid prices and the

consumed aircraft capacities, denoted by h_{wt} and h_{vt}, respectively. Inequality 3.14 on the other hand gives the description of the constraints of the consumed capacity at each period. The point of focus of this process is to determine the maximum bid price such that the eventually yielded revenue is maximised as well.

Assuming that all the information relating to the expected demands (such as the weights, volumes, individual profit rates and the order in which they will be arriving) are all known and are all defined as;

$$S = \{(d_{w1}, d_{v1}, r_{d1}), (d_{w2}, d_{v2}, r_{d2}),\ldots, (d_{wj}, d_{vj}, r_{dj})\}$$

The terms (d_{wj}, d_{vj}, r_{dj}) define the corresponding weight, volume and the individual profit rate of the j^{th} demand. The chronological arrivals of the booking requests (demands) are merited such that if j is less than 1 (j<1) then the demand request characterised by (d_{wj}, d_{vj}, r_{dj}) arrives before (d_{w1}, d_{v1}, r_{d1}) and vice versa. Using the above explanation, a demand scenario defined by the following expression can be realized in the future:

$$S = \{(d_{wj}, d_{vj}, r_{dj})\} \text{ where } j = 1, 2, 3, \ldots, n.$$

Depending on the rate at which the booking requests arrive, joint distribution function of the weight and volume as well as the profit distribution rate, all the possible demand scenarios expected in the future may be determined with the assumption that the these scenarios do not depend on each other.

Letting $\xi = \{S_i = \{(d^i_{w1}, d^i_{v1} + r^i_{d1}), (d^i_{w2}, d^i_{v2}, r^i_{d2}),\ldots, (d^i_{wn}, d^i_{v}, r^i_{dn})\}$, i = 1, 2, 3, …, m.

- S = the i^{th} scenario.
- n_i = the number of booking requests in the i^{th} scenario (S_i).
- m = the number of possible scenarios anticipated in the future.

Simulation of arrivals is done with in a specific period of booking. The booking period commences at the time horizon and terminates when the time horizon becomes zero.

(From t=T to t=0), which in the case of an air cargo, this time interval translates to not more than a week before the departure of the flight in question while in the case of passenger service section, the time interval could be as long as a year. During this time period, booking requests are received in a random manner and each time the requests are encountered, revenue management must make a decision regarding the acceptance or rejection of such requests. Poisson's process is used in developing a model of such kind. As indicated with Poisson's process of arrival, booking requests are received randomly at a rate λ.

For instance, a request can either be approved or refused, which makes it possible to use a high and low binary digits representing acceptance and refusal, respectively, for positive logic and or refusal and acceptance respective for the case of negative logic.

The decision making process in each scenario involves approval or rejection of the incoming booking requests and will be in accordance with the conditions described in inequalities 3.13 and 3.14. This can then be followed by the corresponding calculations of the expected revenues from each scenario. Expected revenue from all scenarios can easily be calculated upon the determination of the probability of the occurrence of scenario *i*.
Now, the optimal bid prices (h_{wt}, h_{vt}) can then be calculated using Mixed Integer Non-Linear Programming (MINLP):

$$\text{Max } E_{\xi} \left[\sum_{j=0}^{ni} r_{dj}^{i}\, x_{j}^{i} \max(d_{wjt}^{i}, d_{vjt}^{i}/\theta_{s})\right] \quad (3.15)$$

s.t ∀ i=1, 2, …, m (flight capacity constraints).

∀ j =1, 2, …, n_i

∀ t=0,..T

$$\sum_{k=0}^{j-1} d_{wkt}^{i}\, x_{kt}^{i} + d_{wjt}^{i} - c_{w} \leq M_1\,(1-x_{jt}^{i}) \quad (3.16)$$

$$\sum_{k=0}^{j-1} d_{vkt}^{i}\, x_{kt}^{i} + d_{vjt}^{i} - c_v \leq M_2\,(1 - x_{jt}^{i}) \quad \text{for j= 1, 2, 3, …, } n_i. \tag{3.17}$$

$$\sum_j x_{jt}^{i}\, d_{wjt}^{i} \leq \text{capaw}_{i,t} \tag{3.18}$$

$$\sum_j x_{jt}^{i}\, d_{vjt}^{i} \leq \text{capav}_{i,t} \tag{3.19}$$

$$\sum_j x_{jt}^{i}\, d_{wjt}^{i} = \text{cuw}_{i,t} \tag{3.20}$$

$$\sum_j x_{jt}^{i}\, d_{vjt}^{i} = \text{cuv}_{i,t} \tag{3.21}$$

∀ i= 1, 2, 3, …, m (these are the bid-price control constraints).

∀ t=0,..T

$$h_{wt}\, d_{wjt}^{i} + h_{vt}\, d_{vjt}^{i} - p_{dit}^{i} \max(d_{wjt}^{i},\, d_{vjt}^{i}/\theta_s) \leq M_3\,(1 - x_{jt}^{i}) \tag{3.22}$$

∀ i=1, 2, 3, …, m (these are the sequential approval constraints).

∀ j=1, 2, 3, …, n_i

∀ t=0,…T

$$c_w - \sum_{k=0}^{j-1} d_{wkt}^{i}\, x_{kt}^{i} - d_{wjt}^{i} + \varepsilon \leq M_1\, c_{jt}^{i} \tag{3.23}$$

$$c_v - \sum_{k=0}^{j-1} d_{vkt}^{i}\, x_{kt}^{i} - \varepsilon \leq M_2\, y_{jt}^{i} \tag{3.24}$$

$$p_{dit}^{i} \max(d_{wjt}^{i},\, d_{vjt}^{i}/\theta_s) - h_{wt}\, d_{wjt}^{i} - h_{vt}\, d_{vjt}^{i} + \varepsilon \leq M_3\, Z_{jt}^{i} \tag{3.25}$$

$$x_{jt}^{i} + 2 \geq c_{jt}^{i} + y_{jt}^{i} + Z_{jt}^{i} \quad (3.26)$$

$$\text{capaw}_{i,t+1} = \text{capaw}_{i,t} - \text{cuw}_{i,t} \quad (3.27)$$

$$\text{capav}_{i,t+1} = \text{capav}_{i,t} - \text{cuv}_{i,t} \quad (3.28)$$

$\forall$ i= 1, 2, 3, …, m (these are the capacity update constraints).

$\forall$ t=0,..T

The $\max(d_{wjt}^{i}, d_{vjt}^{i}/\theta_s)$ can be subtracted by the set of following constraints:

$$\max(d_{wjt}^{i}, d_{vjt}^{i}/\theta_s) = m_{jt}^{i} \quad (3.29)$$

$$m_{jt}^{i} \geq d_{wjt}^{i} \quad (3.30)$$

$$m_{jt}^{i} \geq d_{vjt}^{i}/\theta_s \quad (3.31)$$

$$m_{jt}^{i} \leq d_{wjt}^{i} + M_4 (1 - w_{jt}^{i}) \quad (3.32)$$

$$m_{jt}^{i} \geq d_{vjt}^{i}/\theta_s + M_5 w_{jt}^{i} \quad (3.33)$$

$\forall$ i=1, 2, 3, …, m

$\forall$ j=1, 2, 3, …, n_i

$\forall$ t=0,..T

The decision-making variables used include the following:

- The bid-price corresponding to weight capacity (h_{wt}).
- The bid-price corresponding to volume capacity (h_{vt}).

- Total used weight capacity in scenario i at period t ($cuw_{i,t,}$,i=1, 2, 3, …, m and t=0,1,…T)
- Total used volume capacity in scenario i at period t ($cuv_{i,t}$,i=1, 2, 3, …, m and t=0,1,…T)
- The term x_{jt}^{i} which is 1 whenever the j^{th} demand in the i^{th} scenario arrived at t^{th} time is approved and 0 if the booking request (j^{th} demand) in the i^{th} scenario is rejected. (j= 0. 1, 2, 3, …, n_i and i=1, 2, 3, …, m)
- The binary variable w_{jt}^{i} becomes 1 whenever $d_{wjt}^{i} \geq d_{vjt}^{i}/\theta_s$ and otherwise, it becomes 0
- $X_{jt,}^{i}$ y_{jt}^{i} Z_{jt}^{i} are binary variables (j=1, 2, 3, …, n_i ,i= 1, 2, 3, …, m, t=0,1,…T)

The corresponding parameters used are as defined below

- The weight of the j^{th} demand in the i^{th} scenario arrived at t^{th} (d_{wjt}^{i}, j= 1, 2, 3, …, n_i and i= 1, 2, 3 …m and t=0,1,…T)
- The volume of the j^{th} demand in the i^{th} scenario arrived at t^{th} (d_{vjt}^{i}, j= 1, 2, 3, …, n_i and i= 1, 2, 3, …, m and t=0,1,…T).
- The profit rate of the j^{th} demand in the i^{th} scenario arrived at arrived at t^{th} time period (p_{dit}^{i}, j= 1, 2, 3, …, n_i, i= 1, 2, 3, …, m and t=0,1,…T).
- Available weight capacity in scenario i at period t $capaw_{i,t}$, i= 1, 2, 3, …, m and t=0,1,…T).

where $capaw_{i,1} = c_w$

- Available volume capacity in scenario i at period t $capav_{i,t}$, i= 1, 2, 3, …, m and t=0,1,…T).

where $capav_{i,1} = c_v$

- A very small constant (ε).
- M_1, M_2, and M_3 are large constants.

With respect to the capacity constraints (described by inequalities 3.16 and 3.17), if the cumulative weights and volumes become larger than the available limit of bookable capacity, i.e. the left-hand side of both the inequalities gives a positive value then, such a demand will be rejected, as it cannot be accommodated by the flight in question. In this case, the decision variable becomes zero. This situation is described by inequality 3.22 whenever there is a larger opportunity cost of approving a booking request or demand than the demand's corresponding revenue, as indicated by the left-hand side of the inequality giving a positive value; such a booking request is rejected. Inequalities 3.23 and 3.24 operate in a similar manner as 3.16 and 3.17, thereby ensuring the criterion employed in booking request approval conforms to the requirements described by the bid-price control and capacity constraints. If the approval of a given booking request conforms to the capacity constraints, then the binary variables; c_{jt}^{i} and y_{jt}^{i} = 1. In addition, if the approval of a currently arriving booking request would lead to the utilisation of the flights residual weight capacity, then the decision can be made in its favour. Usuallyε, a small number is added to ensure that c_{jt}^{i} remains equal to 1, even when $c_w - \sum_{k=0}^{j-1} d_{wk}^{i} \delta_k^i - d_{wj}^{i}=0$. The other binary variable Z_{jt}^{i} equals one if and only if the profit earned, due to the approval of the current request, is greater than or equal to the opportunity cost. The inequality 3.26 keeps check on the decision making process in such a manner that it ensures that the current booking request is accepted under the condition that all the requirements are met. Equations 3.27 and 3.28 are used to update available weight and volume capacities after each selling period, according to accepted requests for each scenario.

3.2.4 Modelling the Booking Problem with Fare Classes

For the case of fare class model, the airline is associated with specific fare classes, which are intentionally made different in terms of factors such as charging rates, terms of

service, and the prevailing conditions in each class. This model is the most applicable when pricing the passenger services. Price discrimination is easier to achieve when this model is applied. For instance, the conditions that the first class passengers are subjected to makes them understand why they have to be charged higher as well as enabling them to be able to appreciate the fact that passengers in the subsequent classes deserve to pay a lower price than they do.

The decision to accept or reject a booking request according to this model is a function of the existence of the fare classes such that it depends on whether the former is available or not. The customers' requests can only be accepted if and only if there is space in the particular fare class that they wish to apply for. It is therefore important to consider that the customers who are presenting their applications for a particular fare class are already aware of the conditions and the terms of service related to the class they are requesting to book in which case this won't be decision making factors.

For fare classes' case, again the occurrence of cancellations is assumed to be non-existent. We assumed there are 5 types of fare classes available attended to price discrimination for simplicity. Considering five types of shipments and considering the assumptions, the shipments of category 1 to 4 are shipped on the booking days that are urgent shipments, while the fifth type is carried forward to the next day of shipment. The urgent shipments are charged higher than the flexible cargo type. In addition, the revenue rates among the 4 types are different, for example type 1 represents last call deliveries, which have the highest revenue rates, type 2 requires special handling procedures, type 3 cargos belong to customers that have privileges and type 4 refers to normal cargo. The booking acceptance is carried out by substituting the fifth type of shipment with the flight with the booking request being considered. To consider the urgency in the case of shipment, we planned that at every day of week a flight takes off that contains approved booking requests, arrived at the day of departure or arrived prior to the departure day. The

time horizon is adjusted for a week and all the bookings made in a given week must be handled within that very week, which implies that any type 5 bookings intended for the seventh flight lack flexibility due to the fact that the seventh flight is the final option for which such bookings can settle.

3.2.4.1 Determination of Capacity

The weight, density and volume characteristics of the requests for the fare classes follow the log-normal distribution, the same as introduced in section 3.2.1. However, only difference is that the mean and standard deviation parameters of log-normal distribution vary for different classes. The volume can be calculated similarly by multiplying the weight and inverse density of related fare class i; $V_i = W_i D_i$.

The determination of airplane capacity involves the determination of both weight and volume capacities, expressing them as a fraction of the total—services demand. The volume and weight capacities expressed as a fraction of the total demand are denoted by $\mathcal{Z}_v$ and $\mathcal{Z}_w$, respectively. $E(W_j)$ and $E(V_j)$ are assumed to be the anticipated total bookable weight and volume, respectively, for a single flight. Now:

$$C_{wj} = \mathcal{Z}_{w.} E(W_j) \tag{3.34}$$

$$C_{vj} = \mathcal{Z}_{v}. E(V_j) \tag{3.35}$$

3.2.4.2 Booking Arrival Trend

For this case, we used a probabilistic approach to determine the behaviour of upcoming requests rather than adopting the Poisson process. To simulate the booking

process, the incoming bookings vector would be used, if first created starting with the time instant t = 130 and the probability of the arrival of the i^{th} cargo type at time t is denoted by p_{it}.

The probability that no arrival is to occur is 1 in some periods, since the booking period is taken to be 70 for every single flight, at most, one request could occur at each period. The deterministic fields of the booking vector are booking type, flight in question, weight of shipment, volume of the shipment, chargeable weight and the generated revenue.

Given a type i arrival whose probability of occurring is p_{it}, the simulation process begin with picking an anonymous number u ~ U (0,1) where U is the uniform distribution. Given that $p_{i-1,t} < u \leq p_{i,t}$ i Є {1,2…,5}

3.2.4.3 Revenue Linearization

Suppose j denotes a booking request indices, total revenue generated by bookings, ρ_j is given by the expression;

$$\rho_j = r_j \,.\, \bar{\omega}_j \tag{3.36}$$

where r_j denotes the unit revenue (per kilogramme) of booking j and $\bar{\omega}_j$ indicates chargeable weight.

The optimal solution is a good tool in measuring the efficiency with which this model operates. For n number of booking sequence, a specific number of requests must be approved such that the generated revenue is maximised. The acceptable requests should of course not exceed the maximum tolerable volume and weight. A similar procedure as indicated in flexible booking is followed where bookings of the first four types are approved, which are urgent, and the fifth booking type is pushed to the next day. This

problem can be solved as an MINLP problem but first modified by introducing the condition that bookings made for a particular flight must be shipped during the very flight. This condition makes the problem non-linear. If we need to linearise this problem, we introduce another factor R which is the revenue matrix. This matrix contains values of revenue generated when i^{th} booking being accepted on the j^{th} flight. Such that;

$$R = \begin{bmatrix} \rho_{11} & \cdots & \rho_{1j} & \cdots & \rho_{1L} \\ & \vdots & & \ddots & \vdots \\ \rho_{i1} & \cdots & \rho_{ij} & \cdots & p_{iL} \end{bmatrix} \quad (3.37)$$

ρ_{ij} = -M4 if j not $\in F_i$ and

$\rho_{ij} = \rho_i$ if $j \in F_i$

F_i in this case represents the set of the possible flights for the i^{th} booking and M4 is a large constant and L denotes the total number of flights which is 7 for this case. The i^{th} flight in this case refers to the flights of types 1 to 4 with a fifth type carried forward if it exists.

The MILP representation of this scenario is as follows;

$$\text{Max z} = \sum_{j=l}^{L} \sum_{i=1}^{n} r_j \,.\, \bar{\omega_j}\, x_{ij} \quad (3.38)$$

$$\text{s.t. } \sum_{i=1}^{n} w_i\, x_{ij} \leq Cwj \quad \forall j \quad (3.39)$$

$$\sum_{i=1}^{n} v_i\, x_{ij} \leq Cvj \quad \forall j \quad (3.40)$$

$$\sum_{J=1}^{L} x_{ij} \leq 1 \quad \forall i \quad (3.41)$$

where x_{ij} is a binary variable, becomes 1 if booking type *i* is carried by flight *j*, 0 otherwise.

The chargeable weight$\bar{\omega}_j$, is modelled based on disjunctions; heavier shipments get a certain amount of discount. To revise the model to establish this charging approach, we should introduce a new variable and parameters defining the chargeable weight brackets for each fare class. Binary variable $k_{i,l}$ becomes 1 if bracket *l* for class *i* is selected, otherwise it becomes 0. wL_l and wU_l denotes the lower and upper limits for chargeable weight brackets. The additional constraints appear as follows:

$$\bar{\omega}_j \geq \sum_l wL_l \; k_{il} \quad \forall i \tag{3.42}$$

$$\bar{\omega}_j \leq \sum_l wU_l \; k_{il} \quad \forall j \tag{3.43}$$

$$\sum_l k_{il} = 1 \tag{3.44}$$

The chargeable weight $\bar{\omega}_j$, can also be modelled similar to described in equations between 3.29 and 3.33 in previous section.

Chapter 4

RESULTS

4.1 Bid-Price Simulation for Single-Leg Booking Control Problem

Once the models expected to handle the described problems have been designed, which for this instance is the determination of the most appropriate bid-price, it becomes necessary to test how effectively they function. First, a simulation is created to determine the best of the bid prices with respect to the weight and volume of the shipments. This is then followed by running a programme that identifies the average price at which booking requests can be approved, by solving a collection of 1,000 sample cases.

Through bid-price simulation, the most appropriate price at which booking requests can be accepted is solvable. This is done by feeding different values of the shipments' dimensions, which in this case are volume and weight. Several adjustments are made and at each point, a simulation is run to detect how the values respond to the prevailing conditions. Several simulations will yield the most acceptable price of acceptance, which can then be adopted as the new bid-price.

The values of choice in the simulation experiments provided are actually predictions. These values follow the requirements for actual airline parameters. The volume has deliberately been assumed to be $60m^3$, due to the fact that this manipulation will still be accommodated by the inverse density requirement. The IATA ratio is taken at 1:6, universally. We run the problem for five different scenarios by altering the mean and standard deviation of weight and volume distributions for each scenario. The probability of occurrence of each scenario is equally likely. As introduced in the Problem Statement part, to stimulate demand arrivals, the time horizon is divided 1,000 time units, and Poisson pro-

cess is conducted with λ=0.0225, whereas the decision period is divided into 130 time intervals. At every decision time period Poisson process is operated. The distribution parameters for size and the corresponding revenue are illustrated in the table below.

Table 4.1: The weight and volume capacities of a certain flight

Weight capacity, C_w (kg)	10000
Volume capacity, C_v (m^3)	60

Table 4.2: Distribution parameters for revenue and size of booking requests

	Mean, μ					STD, σ				
Scenario	1	2	3	4	5	1	2	3	4	5
Weight,w	1500	1000	1000	1000	500	2000	2000	1500	1000	1000
Density,D	0.006	0.005	0.0045	0.003	0.0025	0.003	0.003	0.003	0.003	0.003
Rate, r	2.5	2.5	2.5	2.3	2.0	1.0	1.5	1.1	1.0	0.8

Table 4.3: The Poisson's process parameters

Time period, T	1000
Booking rate λ	0.0225

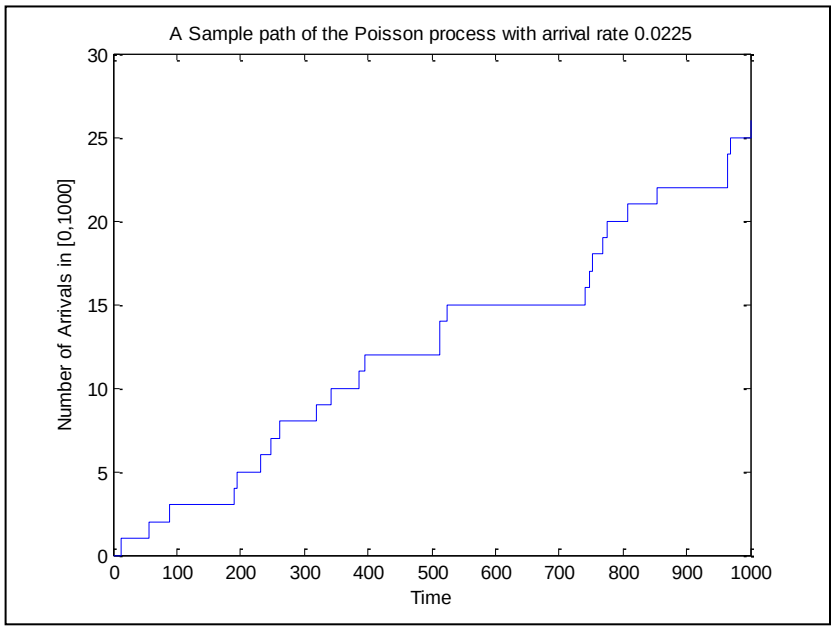
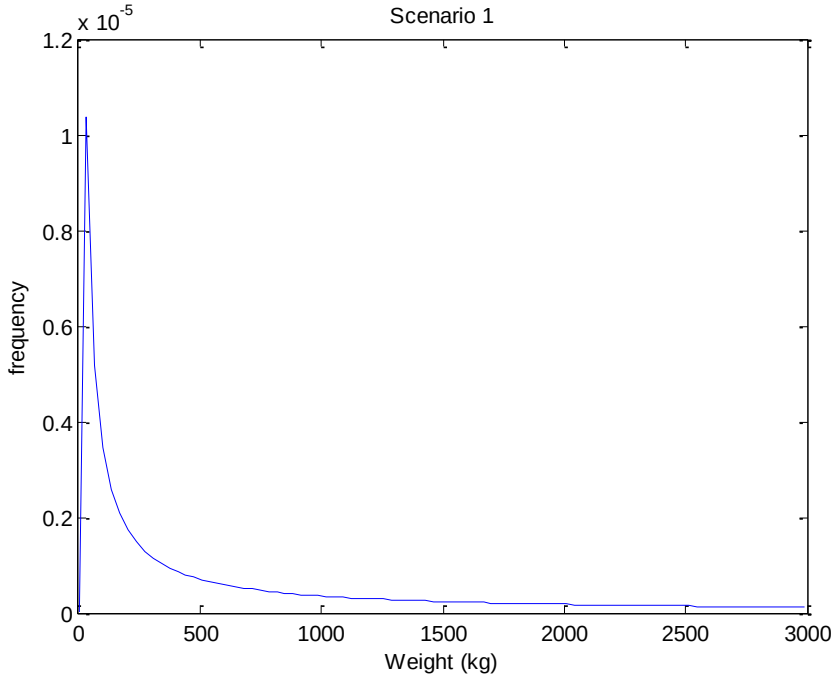
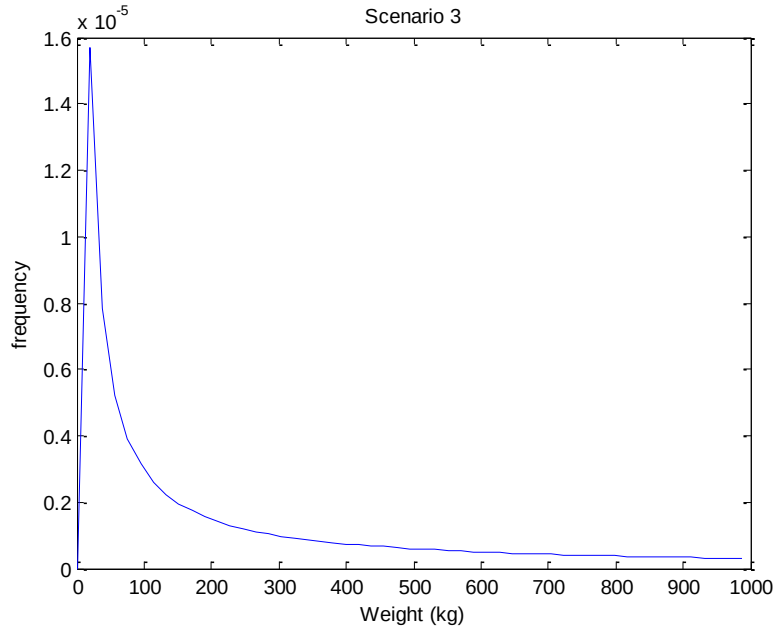
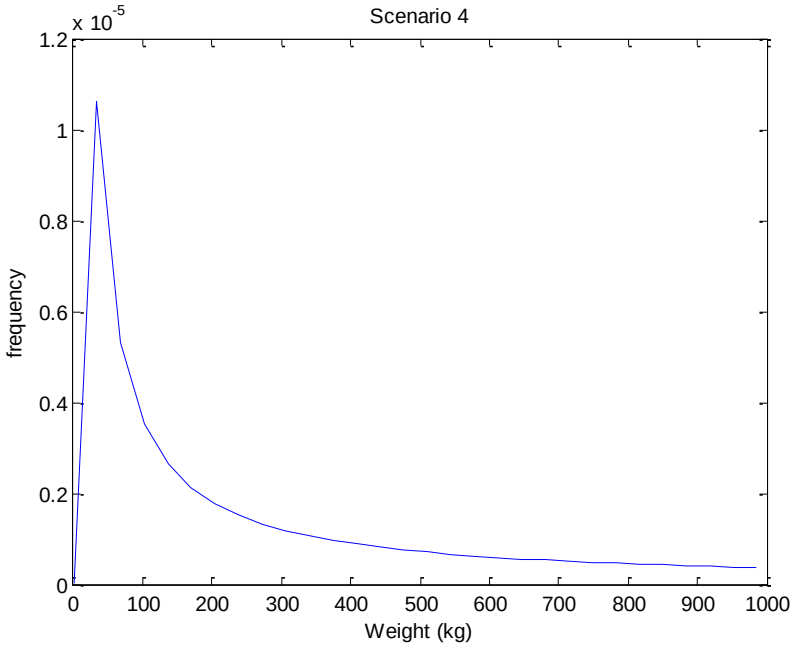


Figure 4.1: Sample Poisson Process Demand Arrivals




Scenario 3
x 10^-5
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
frequency
0
100
200
300
400
500
600
700
800
900
1000
Weight (kg)


Scenario 4
x 10^-5
1.2
1
0.8
0.6
0.4
0.2
0
frequency
0
100
200
300
400
500
600
700
800
900
1000
Weight (kg)

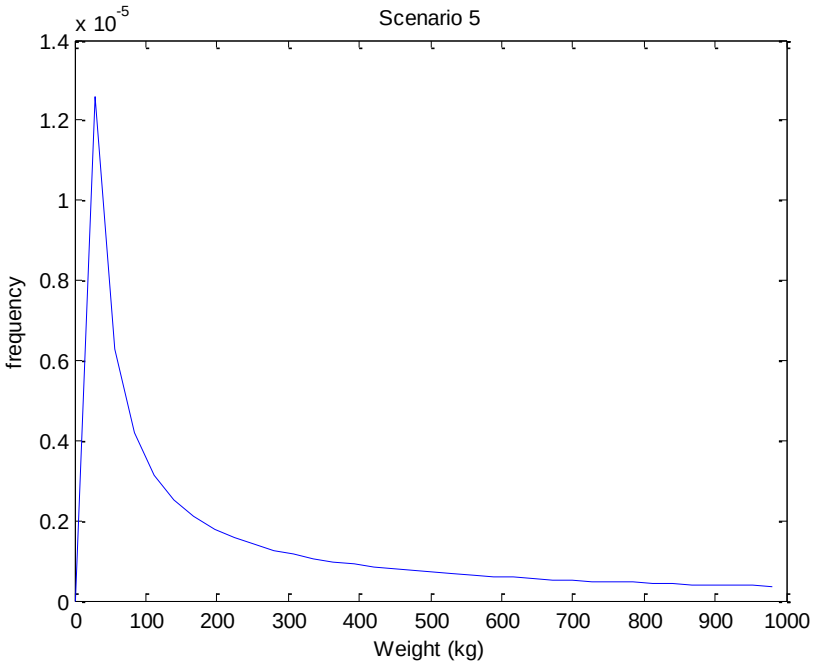
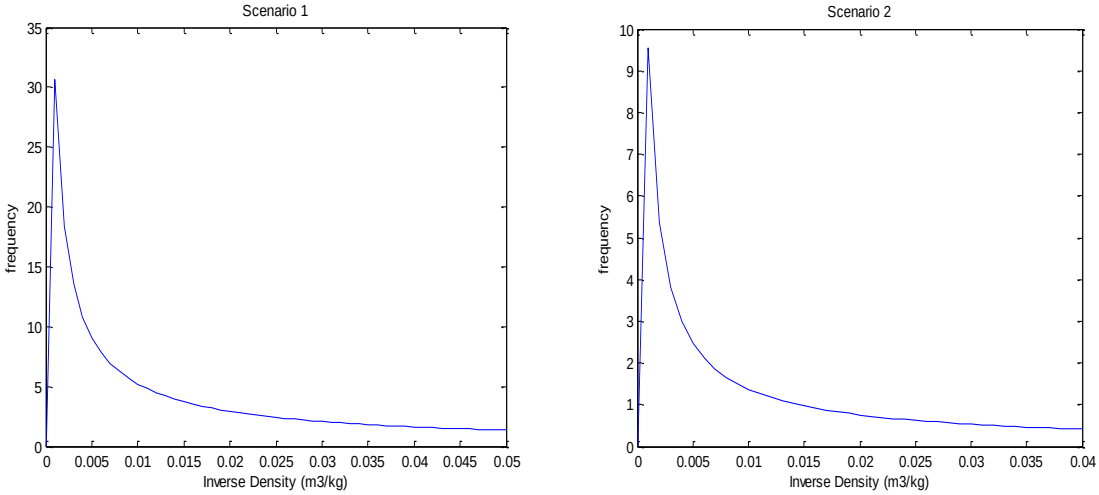


Figure 4.2: PDF of Weight Distributions for Different Scenarios



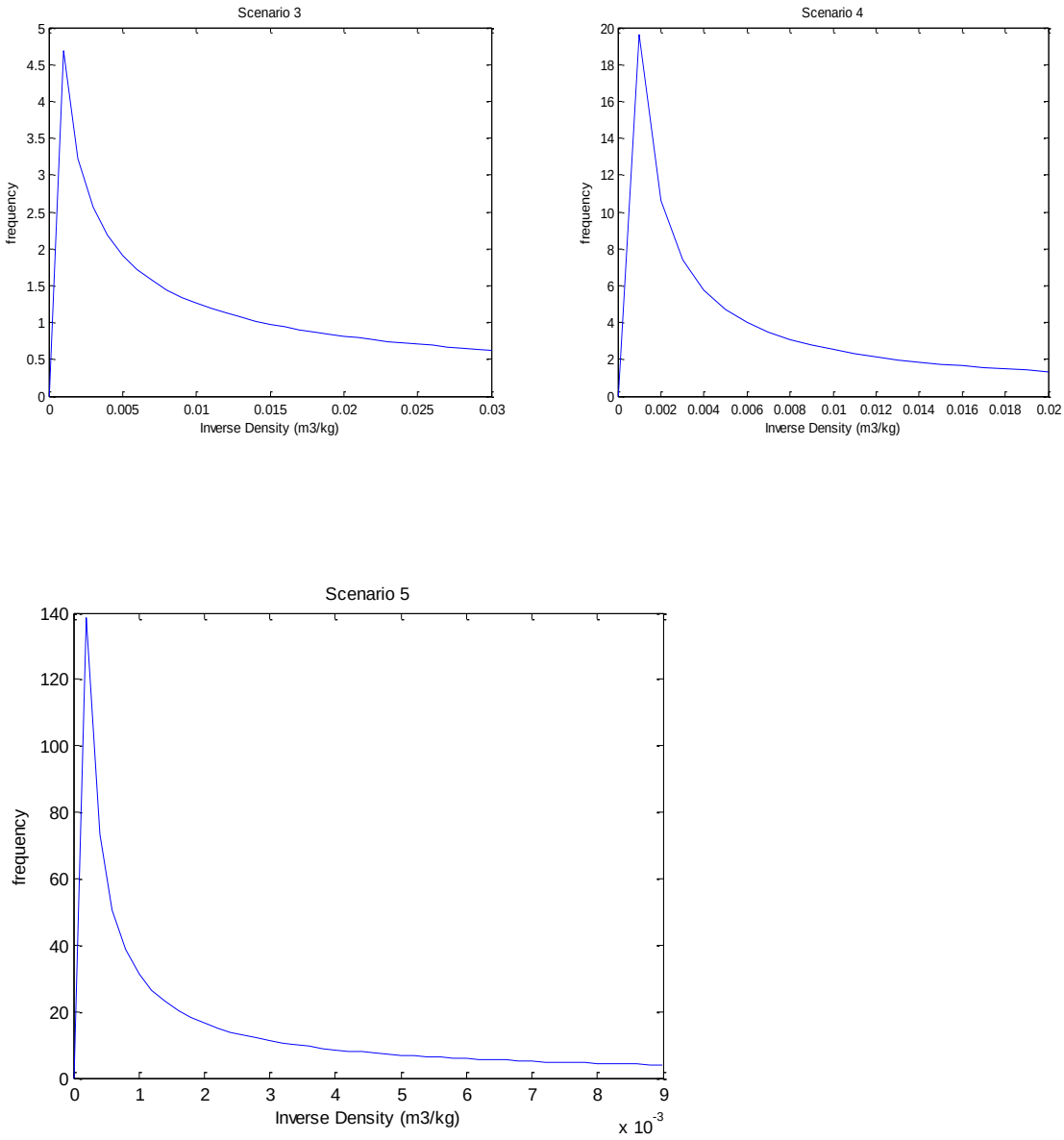


Figure 4.3: PDF of Inverse Density (m^3/kg) Distributions for Different Scenarios

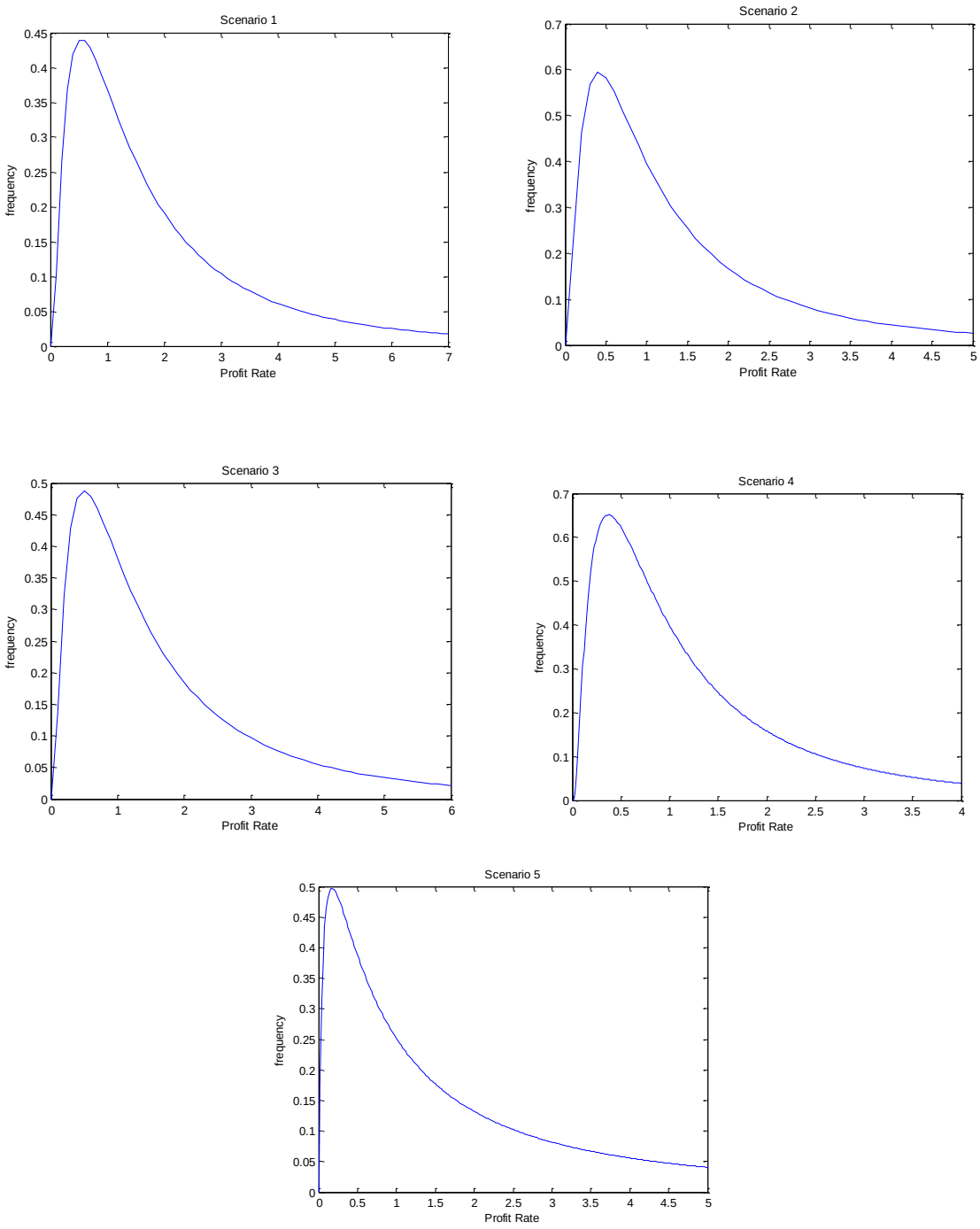


Figure 4.4: PDF of Profit Rate Distributions for Different Scenarios

We applied a Receding Horizon Approach for making decisions in a dynamic environment. The Receding Horizon Approach involves decisions that must be made in the relevant period, based on a deterministic forecast of future events, which are based on what we know at time *t*. We then use this forecast to solve the problem that extends over a planning horizon, but only implement the decision for the immediate time period.

4.1.1 Benchmarking Problems

The first policy chosen for the benchmarking problem in this particular problem is the First Come First Served technique. It is preferred because, through it, the derived policies can easily be compared with the ideal revenue generation in the absence of revenue management. This technique only accepts booking requests if available capacity on the airplane in accordance with the dimensions of request exists. The second benchmark problem relates to derivation of bid-prices. Static bid-prices ignore the intensity of demand over time; they are stable at every decision period. Dynamic bid-prices can be adjusted differently at each period of time, according to demand pattern. At every rolling period, the bid-price problem is resolved to obtain new prices. If remaining capacity until departure is high, then the prices become lower. If remaining capacity is low, which implies demand is high, bid-prices become higher. The formulation is operated along with a dynamic environment, which demands are incorporated stochastically. The threshold values for demand are calculated for certain periods, according to time remaining to departure. The optimal threshold values are for the related period. Weight capacity utilization and bid-prices obtained with respect to time period are illustrated in Figure 4.1 and Figure 4.2, and volume capacity utilization and bid-prices are demonstrated in Figure 4.3 and 4.4 for all five scenarios. Finally, results obtained from these three proposed approaches are compared in

terms of revenue generated over the planning horizon and total capacity utilization in both dimensions.

The consequences are that the revenue generated using the static model become slightly higher than generated by FCFS, despite the fact that there will be an overall high output, as far as revenue generation is concerned. The prices for the static bid-price case are calculated as hw=1.88 for weight and hv=319.65 for volume by applying this method. These are the minimum prices that a booking request can accept for using a unit of capacity. If the bid-prices obtained using the dynamic model is compared with those of the static model, it can be seen that the revenue values for the former exceed those of the latter by up to ten per cent. The results from such comparisons are illustrated below.

Table 4.4: Comparison of Dynamic Approach vs. FCFS and Static Model

	FSFC	Static	Dynamic
Revenue	28522.25	36236.31	37176.00
hw, hv	-	1.88, 319.65	0-4, 230-650
% weight capacity utilization	97	83	95
% volume capacity utilization	95	76	90
Percentage OPT	77%	85%	100%

Table 4.5: Summary of GAMS run for Dynamic Single-Leg Booking Control Problem

Execution time (sec)		36,387
Expected Revenue Generated		37176.00
Weight Capacity Utilization		9874.69
Volume Capacity Utilization		58.532
# of Constraints		25,668
# of Variables	# of Binary Variables	3,900
	# of Continuous Variables	6,006
	# of Integer Variables	7,800
	Total # of Variables	17,706
# of Iterations with Baron		26,103

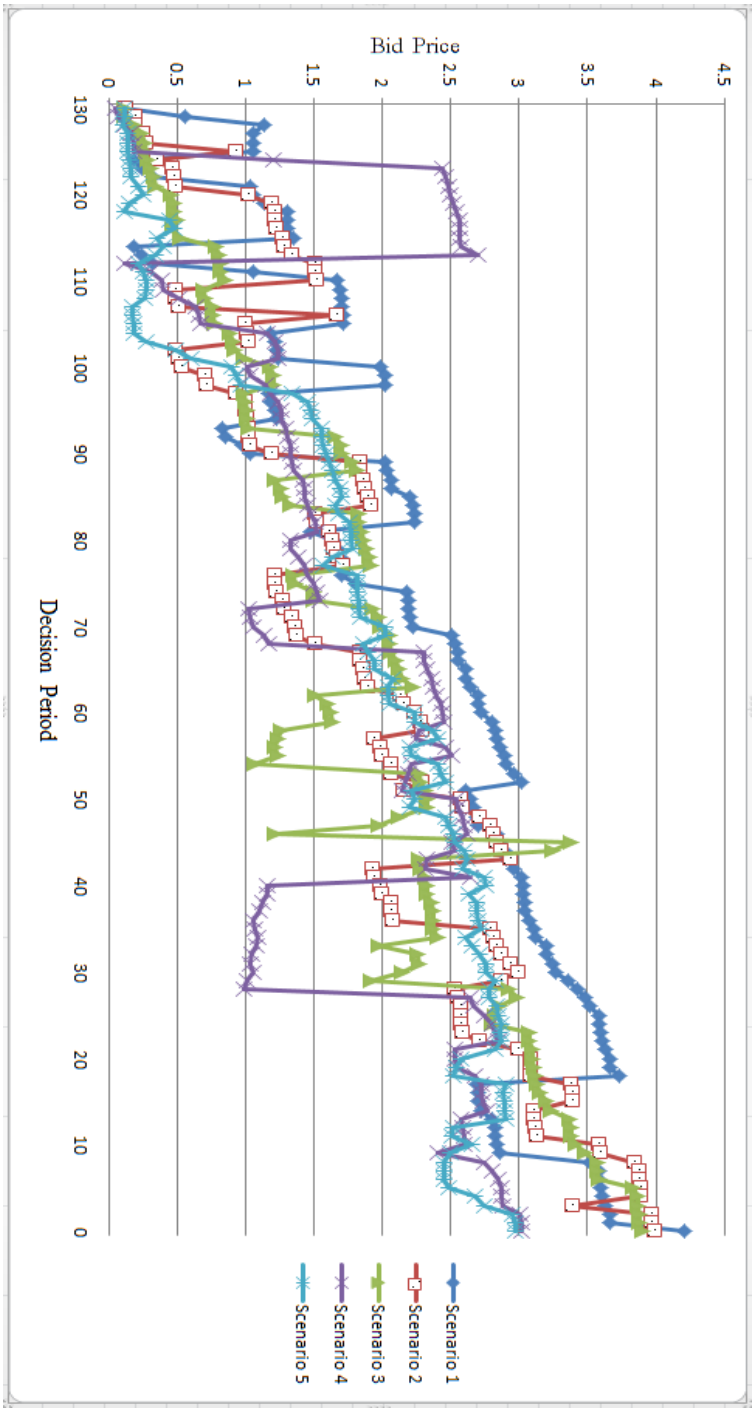


Figure 4.5: Weight Bid Price vs. Time Period Graph for Five Scenarios

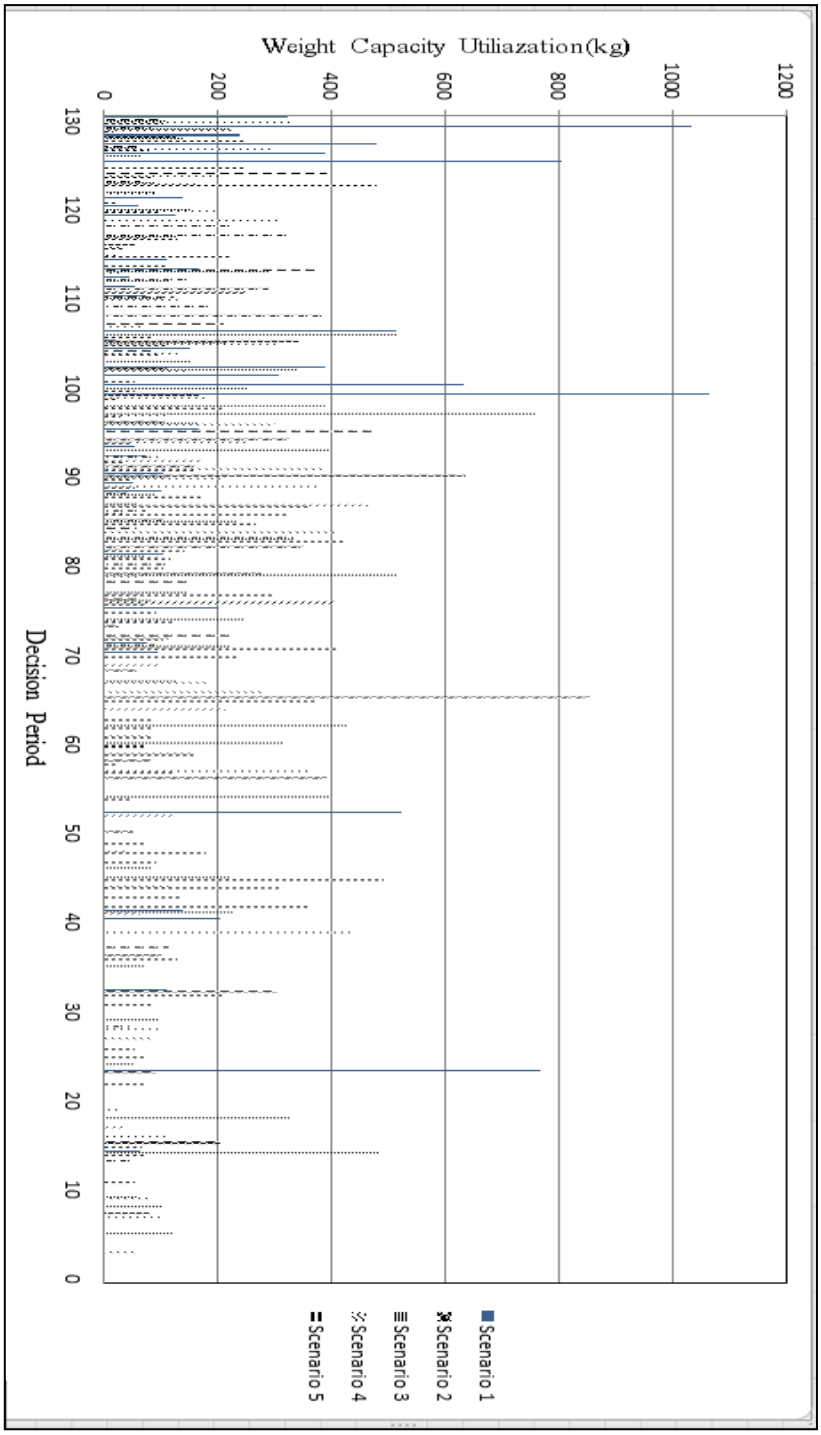


Figure 4.6: Weight Capacity Utilization vs. Time Period Graph for Five Scenarios

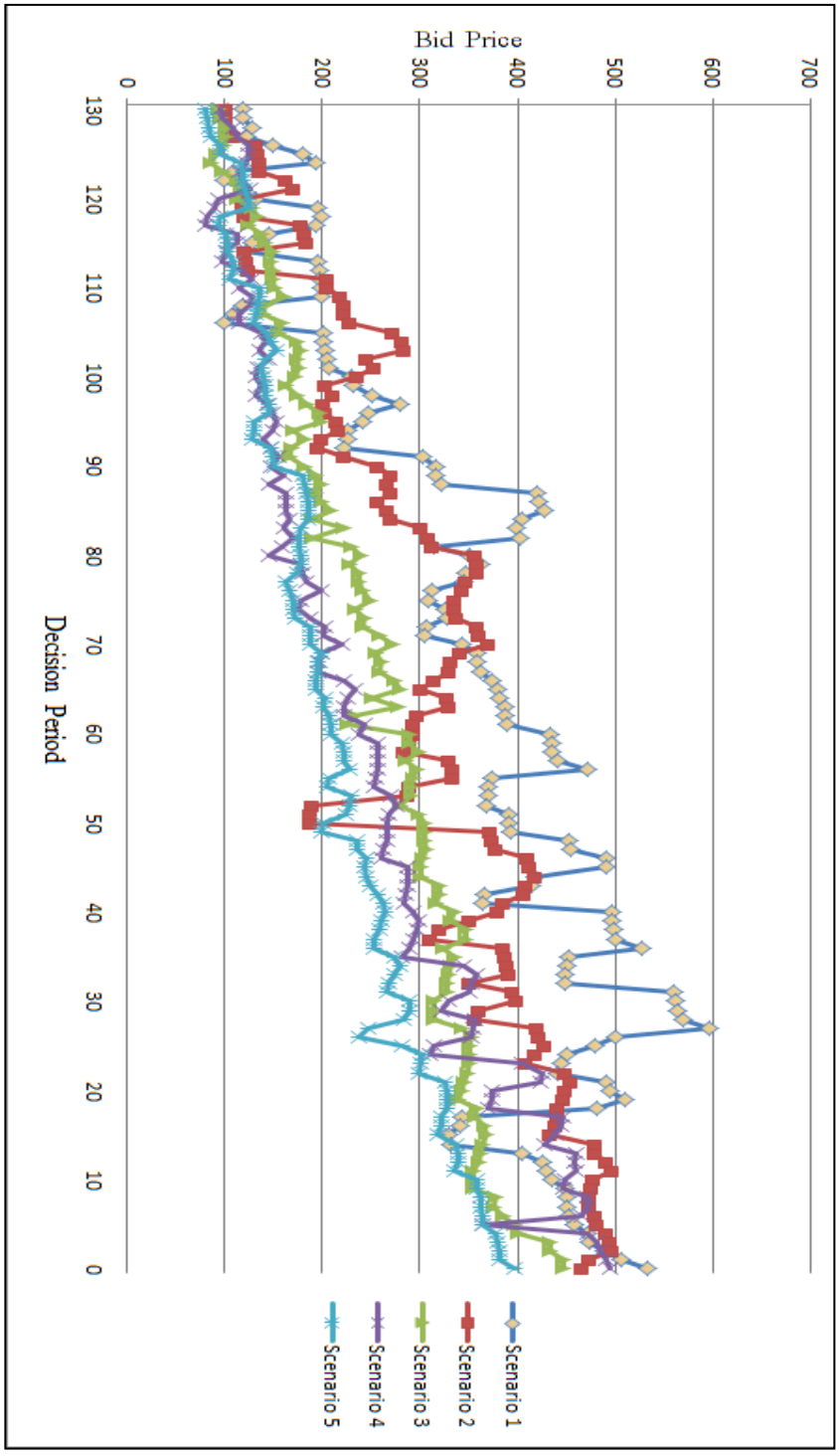


Figure 4.7: Volume Bid Price vs. Time Period Graph for Five Scenarios

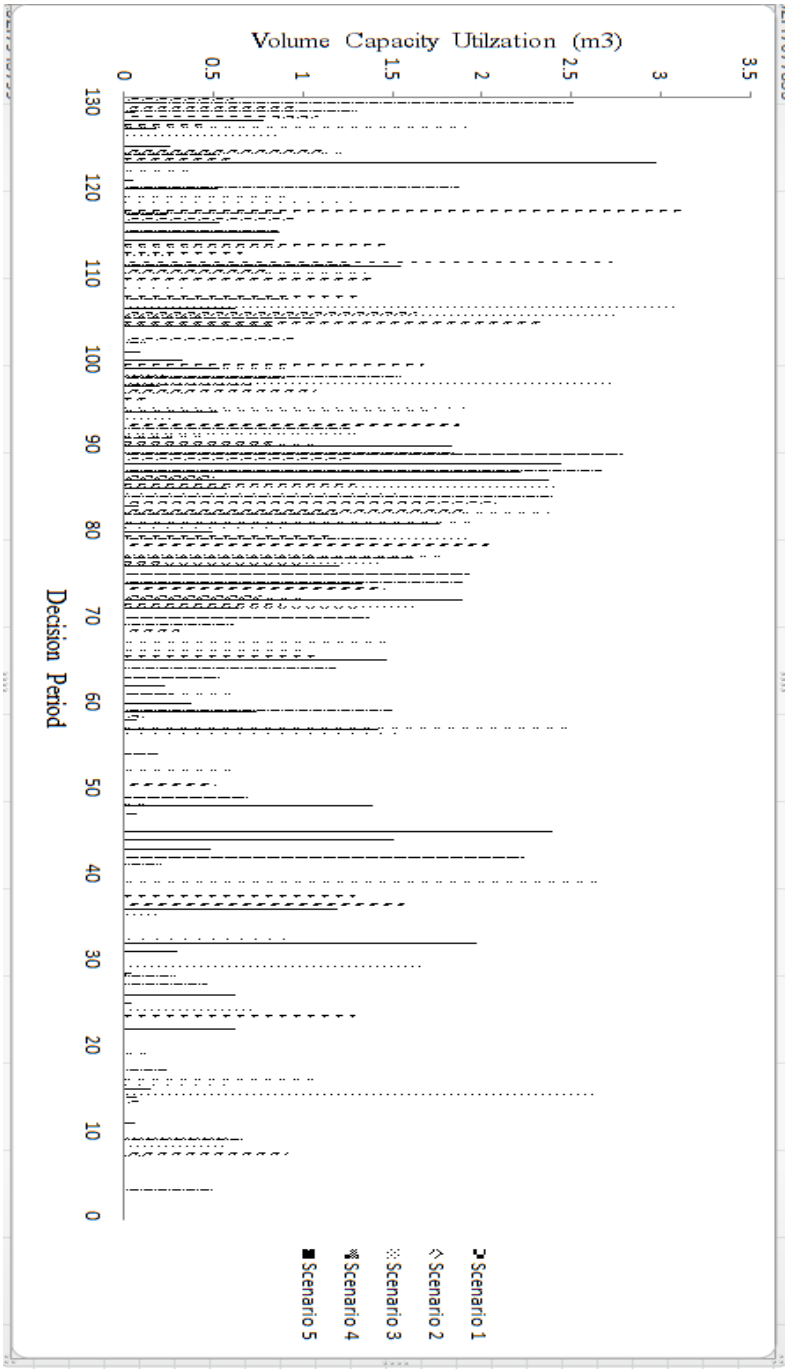


Figure 4.8: Volume Capacity Utilization vs. Time Period Graph for Five Scenarios

Figure 4.6 and 4.8 illustrate the capacity utilised by the approved bookings in terms of volume and weight. It can be observed that booking process tend to utilise most of the capacity at the initial periods. Since the bid-prices increase near the departure time, which can be inferred by Figure 4.5 and 4.7, the arrival probability of booking requests are low at further periods. Therefore, the flight takes off under occupied risk and requests arrived at the beginning of selling season are more likely to be accepted.

4.2 Bid-Price Simulation for Booking Control Problem with Fare Classes

It is a common tendency of revenue management that a fare class responsible for low revenue generation is assigned a specific limit of booking with an implication that the extent to which the booking of a low-revenue generating fare class can be achieved is controlled. This is achieved by limiting the capacity available for shipments in such a fare class. For this particular model, the low-revenue generating fare class is that which is made up of the fifth type of shipments. The assumption made in this problem is that every flight leg must be partly loaded with the type five shipments and there can never be full utilization of the plane's entire volume and weight capacity without the presence of these types of shipments or without the low-revenue generating fare class being occupied. This unavoidable fact leads to the need to determine exact or approximate booking limits. The time horizon is divided into 70 periods for a week and the probability of a shipment type arriving in a specific day of flight is given. The revenue function is modeled based on disjunctions. A numerical approach can be followed using different chosen values as illustrated in the tables below.

Table 4.6: Probability Matrix for Shipment Types Arrived at Every Period in a Week

	70-61	60-51	50-41	40-31	30-21	20-11	10-1
Type 1	0	0	0	0	0.1	0.2	0.3
Type 2	0.005	0.005	0.005	0.005	0.1	0.05	0.05
Type 3	0	0	0.1	0.1	0.15	0.05	0
Type 4	0.15	0.15	0	0	0	0	0
Type 5	0.08	0.12	0.1	0.16	0.15	0.07	0.02
p_{ot}	0.72	0.68	0.75	0.69	0.5	0.63	0.63

Table 4.7: Log-Normal Logarithmic Weight and Density Parameters for Shipment Types

Type	μ^w	σ^w	μ^d	σ^d
1	500	1000	0.006	0.00338
2	500	1000	0.006	0.00338
3	1500	1000	0.006	0.00338
4	1500	1000	0.006	0.00338
5	1000	800	0.006	0.00338

Table 4.8: Profit Rate *r* Matrix (ϖ =chargeable weight)

Type	ϖ <100	100≤ ϖ <500	500≤ϖ <1000	ϖ >1000
1	4.00	3.50	3.25	3.00
2	3.00	2.50	2.25	2.00
3	2.00	1.75	1.50	1.25
4	1.50	1.25	1.00	0.75
5	1.00	0.80	0.60	0.40

There are differences in the parameters associated with different types of shipments, mainly due to the fact that corresponding factors of motivation also differ. The weight and volume capacity figures are lower than the cheaper ones for obvious reasons, which is the fact that lower prices are more motivating compared to expensive charges. The consolidation of cargo type of shipments is usually done by forwarders, which imply that such shipments are those that have been collected from different shippers hence a larger mean weight. The expected weight and volume of each flight is calculated as 22500 kg and 135 m^3, respectively, when ξ_v and ξ_w are taken as 0.9 and using the probability matrix parameters.

4.2.1 Benchmarking Problems for Fare Classes

In the first instance, FCFS policy is adopted for this case to compare the revenue generated by the optimal booking control problem. For simplicity, it is assumed that there is no shipment replacement; the flexibility of the fifth type of shipment is ignored, leading to a very direct policy where the acceptance or dismissal of any incoming booking request is determined by whether or not the available weight and volume capacities are sufficient to

accommodate such shipments. A sample of 1,000 simulations is run with each simulation containing all the bookings done in a spawn of one week.

Second, the FCFS policy is improved to yield a better revenue pattern. Here, shipment type 5 represents the lowest profit orders; if all the upcoming orders at this type are accepted at prior periods, then less capacity remains for the higher revenue classes at residual periods, which results in poor overall revenue generation. With the optimum solution approach, this type of shipment is modelled to use to fulfil the utilised capacity after shipment types with higher profit rates are accepted. On the other hand, FCFS policy allows accepting too many type 5 shipments to maximise the utilised capacity, which results in a dramatic decrease in total expected revenue and leads to this policy become an improper approach. Therefore, to calculate the optimal value for accepting a certain amount of type 5 shipment, we introduce a threshold value β_5, which denotes the percentage of accepted type 5 shipment capacity in terms of weight and volume over the total capacity for each flight. It followed by the introducing capacity threshold limits for all fare classes denoted by $\beta_4, \beta_3, \beta_2$and β_1, sequentially.

We run the simulation for different values of $\beta_5, \beta_4, \beta_3, \beta_2$and β_1 and then the corresponding average generated revenue is calculated. This process is illustrated in Figures 4.9, 4.10, 4.11, 4.12 and 4.13. The optimum, as indicated by the diagram, falls between the points β=0 and β =1. When simulations are run using the two boundary values, it then emerges that the new optimum can be obtained at the point β_5=0.070, $\beta_4 = 0.16, \beta_3 = 0.175, \beta_2 = 0.225$ and $\beta_1 = 0.37$, respectively. In simple terms, this simulation indicates that the amount of low-revenue generated type shipments that should be accepted ought to be as few as possible for the purpose of profit maximisation. This model offers advice to shipping companies to minimise the volume and weight capacity of the low-revenue generating fare classes, but it should be considered that the fifth class of shipments are as important to shipping companies as higher revenue-generating classes, as they are also key

revenue generators. If a shipping company follows this simulation blindly, then there is a risk that shippers whose shipments generate low revenue are discouraged from using the company's services; hence, loss of revenue.

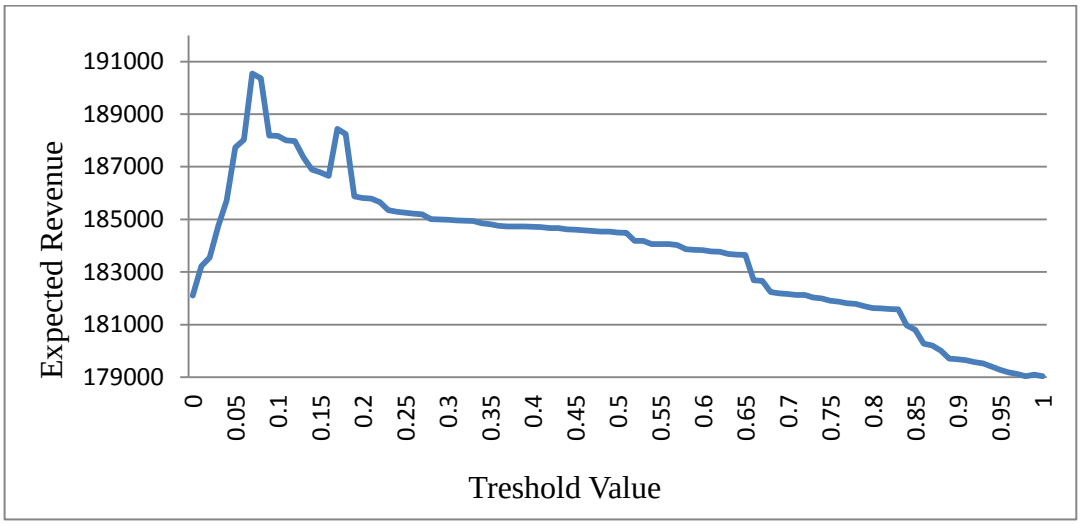


Figure 4.9: Expected Revenue vs. Threshold Limit β_5 for Type 5 Shipment

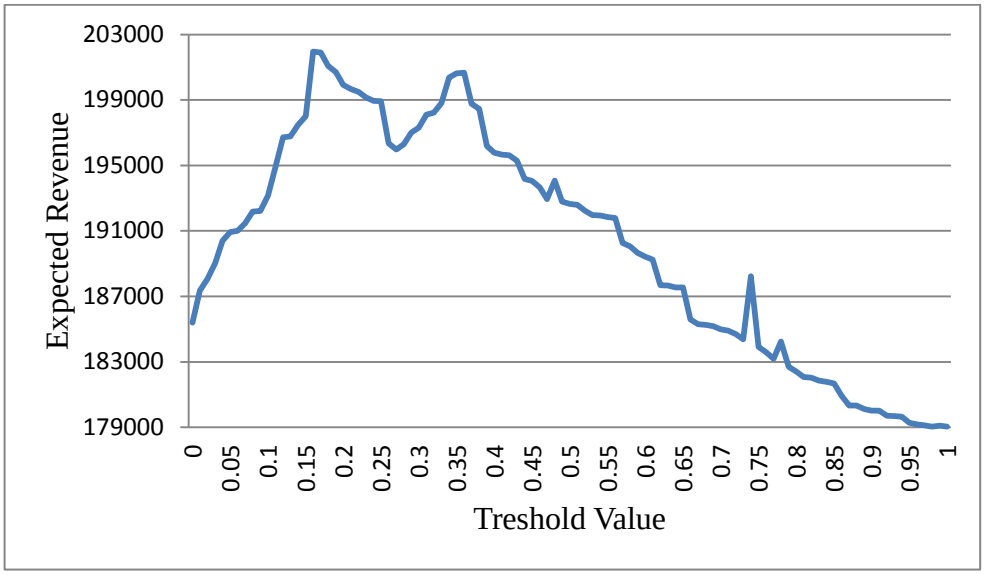


Figure 4.10: Expected Revenue vs. Threshold Limit β_4 for Type 4 Shipment

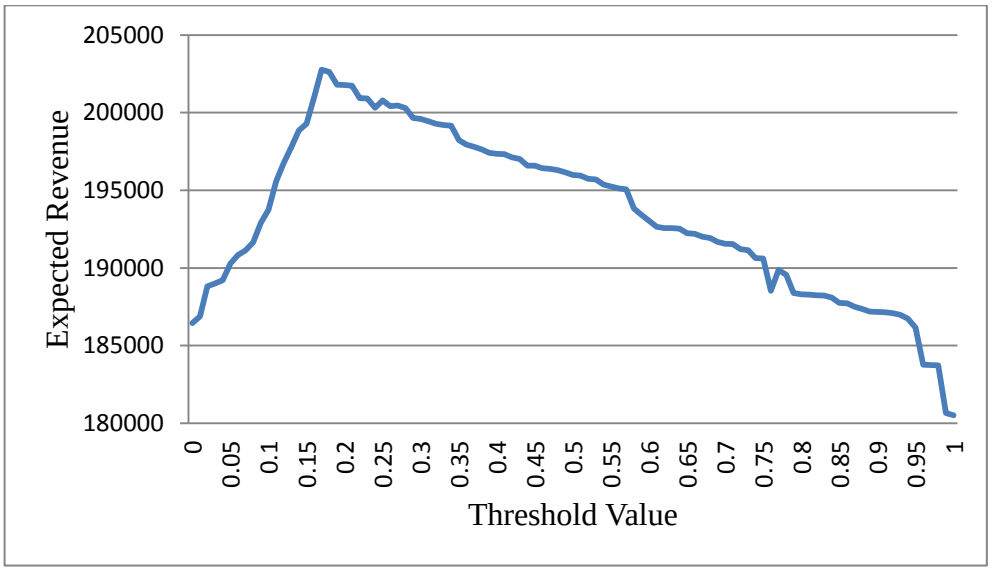


Figure 4.11: Expected Revenue vs. Threshold Limit β_3 for Type 3 Shipment

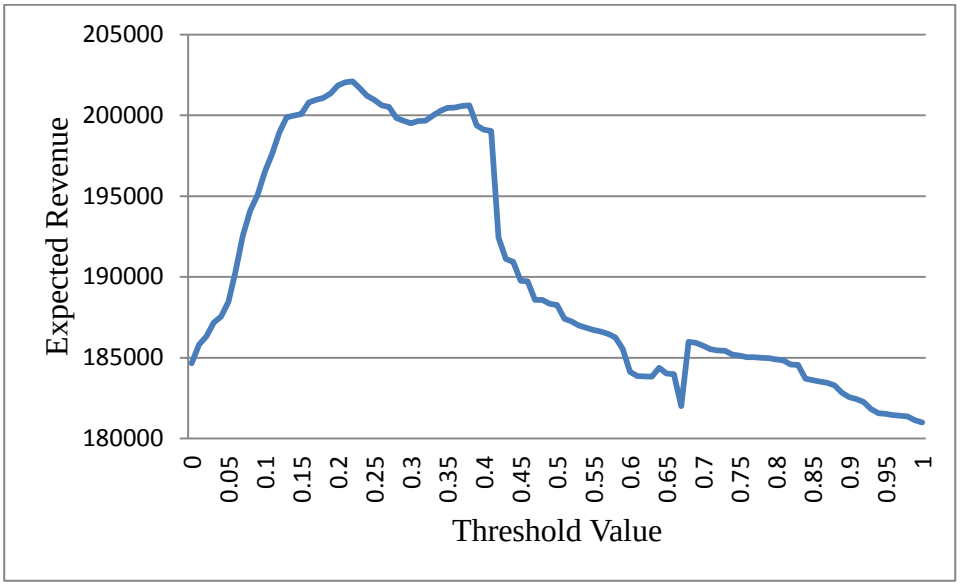


Figure 4.12: Expected Revenue vs. Threshold Limit β_2 for Type 2 Shipment

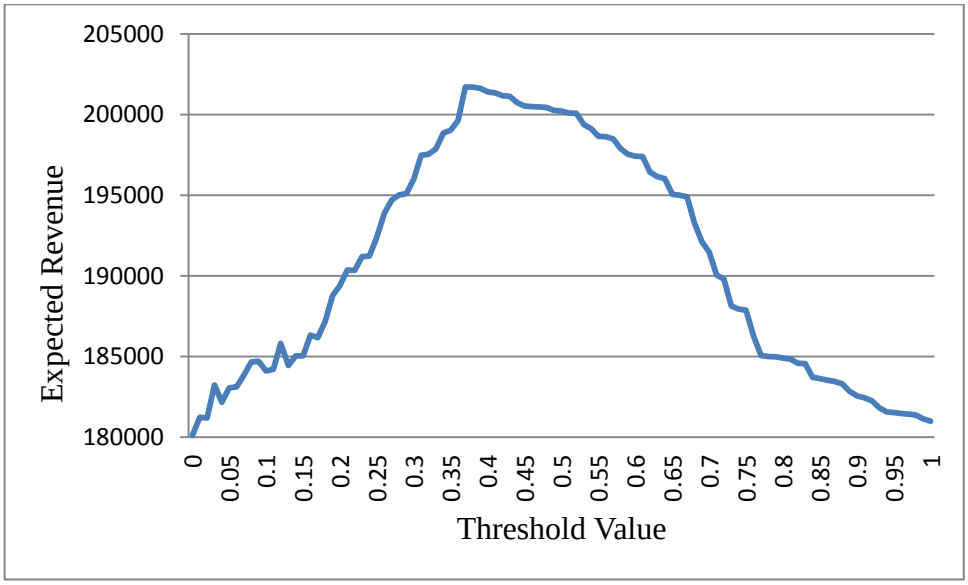


Figure 4.13: Expected Revenue vs. Threshold Limit β_1 for Type 1 Shipment

Table 4.9 summarizes the effect of using threshold limits on capacity reserved for each class. The threshold-booking limit is applied for only type 5 shipments at first. Then, we extend the application of using threshold limits for two classes—type 5 and type 4. Each time we added a limit for one more class and calculated the revenue gained. According to results, implementing limits for low revenue classes, such as classes 4 and 5, yields higher revenue than the FCFS technique. However, when the threshold limit approach is used for higher revenue classes, the revenue started to decrease due to low loading factors.

Finally, the developed dynamic optimal booking model is applied, which presented at Chapter 3. The results obtained by implementing these approaches are tabulated in Table 4.10 and 4.11. If the concept of the First Come First Serve policy is applied, then the hypothetical optimum is in excess by approximately 30 per cent. Using the optimal threshold limit approach results in 13.6 per cent increases in revenue, rather than directly applying the FCFS policy. In essence, we have a double increment such that the hypothetical optimum offers a 30 per cent increment, while FCFS with threshold limit model offers an approximately a 14 per cent increment, all with respect to the optimum obtained using FCFS policy. In fact, it is logical that further increments can be achieved if the properties of the shipments are factored in the optimisation process.

Table 4.9: Results Comparison of Using Threshold Limits for Different Classes

	β_5	β_5, β_4	$\beta_5, \beta_4, \beta_3$	$\beta_5, \beta_4, \beta_3, \beta_2$	$\beta_5, \beta_4, \beta_3, \beta_2, \beta_1$
Revenue	190552.23	202946.28	202082.8	201679.13	200131.47
% weight capacity utilization	87	85	86	84	81
% volume capacity utilization	91	88	85	82	80
Percentage OPT	89%	95%	94%	92%	91%

Table 4.10: Results Comparison of FCF and Optimal Policies

	FSFC	Optimal
Revenue	168507.09	220508.17
# 5 Shipment acceptance ratio	0.328	0.236
% weight capacity utilization	89	94
% volume capacity utilization	88	92
Percentage OPT	75%	100%

Table 4.11: Summary of GAMS run for Booking Control Problem with Fare Classes

Execution time (sec)		215,64
Total Revenue Generated		220508.1
Weight Capacity Utilization		21950.72
Volume Capacity Utilization		130.332
# of Constraints		15,361
# of Variables	# of Binary Variables	3,835
	# of Continuous Variables	7,670
	# of Integer Variables	5,606
	Total # of Variables	17,111
# of Iterations with Baron		25,668

4.3 Relevance of the Model

The models used in this thesis are of high relevance to the entire air cargo industry. The models can be diversified such that each model is applied in departments where they are best suited. For every fare class under consideration, it is advisable to determine the corresponding threshold limit, rather than only booking type 5. The so-derived booking limit should strictly conform to the rule of revenue maximisation. This can be verified when a maximum possible load factor is attained. The proposed dynamic linearised optimal model is preferred for the optimisation.

Most airlines able to operate successfully have been involved in revenue management practises in such a manner that threshold limit is heavily considered and its results accompanied by advisable conditions. This way, revenue maximisation has become achievable. The bottom three fare classes may be considered unproductive by individuals who lack sufficient knowledge. However, effective implementation of threshold limit optimisation can lead to unbelievably high income from these classes. In fact, the revenue generated when appropriate conditions are provided is close to the hypothetical anticipation, as shown by the models in this thesis. It is advisable that the FCFS method be used as the default method under careful supervision with the back-up plan. In the event unreasonably high deviations occur, then the limits can be carefully adjusted to meet the airlines' expectations.

Knowledge about the results produced by each model is as important as knowing the models themselves. With the appropriate information concerning the diverse models, a user is always able to make a choice on which of the models to apply, depending on the context and or the nature of the market demand. For this reason, it is of much relevance that users acquaint themselves with knowledge concerning all available models. For instance, a user

whose knowledge is restricted to a model that leads to a large number of threshold limits may optimally use this model with the thought that it is operating well, but may end up with poor results due to the lack of knowledge about the method having a low load factor.

Chapter 5

DISCUSSION AND CONCLUSION

The air cargo business is by far the least used in local transport systems. This is because many business owners and shippers find it cheaper to use methods such as road and rail when transporting cargo within the locality. It would be more costly to ship goods from one part of the same country to another and hence the statistics supporting the fact that road and rail transport dominate local transportation is justifiable, except on occasions where it is necessary. However, most international transport networks are served by airlines. Companies responsible for the provision of airline services have always exploited the popularity this sector is gaining and the fact that it is no longer a sector but an industry on its own. Many countries of the world heavily rely on the sector as their source of revenue. Other international traders, whether private sector based or governmental who prefer to have their goods quickly shipped have also found this sector a very useful aspect of their business operations.

Airline companies provide a diverse number of services besides dealing with a large variety of customers. The industry is characterised by fierce competition among many producers and care must be taken by those engaged in the business, if they intend to generate reasonable profits. This has brought in the concept of revenue management. With revenue management, businesspersons in this sector are capable of devising techniques that, when properly implemented, can help them cope with the challenges associated with the business by ensuring the revenue their businesses generate is sufficient to earn reasonable profits.

It has been seen throughout this thesis that shipping companies provide several services besides just the transportation of cargo. The services are subdivided into passenger

services, cargo transportation and courier services. The companies diversify operations such as specific flight capacities being meant for cargo while the rest are meant for passenger transportation. In addition, space determination is important in that when subdividing volume and weight capacities, care should be taken such that in the end, maximum revenue generation is achieved.

This thesis took part in close analysis of the airline sector as a revenue-generating industry and went ahead to define the roles played by revenue management in the business. It was observed that revenue management application in the airline industry is not enough to make it effective and save it from the threats it faces. If poor methods are used in revenue management implementation, there is a danger of it being more destructive instead of delivering the expected results. Despite there being a need to conform to the latest trends emerging in this business, it is a tradition of those in the business to stick to their traditional ways of conducting business, making this industry a very conservative one. One of the biggest internal problems this industry has suffered from for a long time is the way to devise a productive system of booking. Revenue management has been used as the tool to solving this problem. Shipper motivation has also been used to encourage consistently using the sector's services. Most shippers who receive quality services from certain shipping companies are likely to come back for more services and vice versa.

In this study, first an optimal booking control model for a single leg flight is proposed. The booking arrivals are conducted using Poisson Process theory. The model is simulated under 1,000 time periods and bid-prices, which imply the minimum acceptance value exceeds the opportunity cost to accept a request are conducted for both using a unit of volume and weight over the rolling horizon. Here, we proposed two MINLP models and compared the revenue gained as a result of applying these models. First, the bid-prices are calculated statically by ignoring the remaining time and capacity on extracting prices. This stands as a NP-hard problem; BARON is selected as first solver and DICOPT as a second

option. Volume and weight of the demands assumed to be distributed log normally. The mean and variance of the r.v.s are varied using a scenario-based approach to increase reliability of data. Expected revenue is calculated using occurrence probability of each scenario. Second, the same booking control problem is solved with a dynamic approach. At the end of each decision period, the previous period is observed in addition with remaining time to departure and the acceptance/rejection decision is implemented according to updated capacity and bid-price information at the related period. According to the results, the requests arrived at initial periods are most likely to be accepted. It is due to avoiding the situation that a flight departs with a low load factor. However, because the bid-prices increase when it is close to departure time, some of the capacity occupied by the bookings arrived at further periods to obtain higher overall revenue. With benchmarking problems, part of the optimal revenue management model is compared to that of the static model and First Come First Served policy. According to results, the dynamic model yields higher revenue at approximately 2.6 per cent, compared to the static model and 30 per cent higher revenue than FCFS.

One of the weapons used by revenue management is the disintegration of its capacities into different fare classes such that the so-formed classes are characterised by different encounters, which makes fare distribution unavoidably discriminative. The booking classes also determine the probability of a booking request being accepted such that the first priority may at some point be given to the upper classes, while the remaining subsequent classes are referred to subsequent flights. The process of revenue optimisation is achieved using a desirable model, which has been proven to yield good results. Several simulations can be run, making different changes after every simulation, until a favourable optimum point is obtained, as it will be indicated by the behaviour of the prototyped set up. We can approach the above dynamic model developed to capture the demand nature such as more urgent requests should be approved with higher rates because they arrive close to

take-off time with a different aspect. We suggested adapting a fare-class approach, alternatively, which is a common technique in passenger revenue management. We assumed five fare classes rating exist with different profit ratios. The Poisson process is not applicable for this case; therefore, we derive a probability matrix assigning arrival probabilities for each class at each period of time. The profit rates are modelled, applying economies of scale to chargeable weights. In the benchmarking problems part, the results obtained from fare the class model is compared with a straightforward FCFS model. As a second approach, we introduced certain threshold limits for each class separately to observe system performance under certain capacity restrictions. At first, we applied threshold limits only for the lowest revenue class 5 that resulted in increasing revenue, compared to FCFS policy. Then we extended applying booking limits to other classes, respectively. The highest revenue is obtained when the limits applied two lowest revenue classes. The revenue decreased when we set limits for high revenue classes because it restricted much of the capacity being utilised by low revenue classes and caused the airplane to take off under-occupied. As a result, optimal booking policy ensuresd higher revenue; 30 per cent more than FCFS policy and 14 per cent more than optimal booking limit policy.

As a future work, cancellation and overbooking policies can be added to model formulation, which is widely used in revenue management practices. In addition, the model is developed only for spot market considering short-term agreements. Long-term commitments also exist in the air cargo business; the model can be extended by involving these types of contracts. No-show is another challenge facing decision makers in this sector. If the customers who book for a certain capacity do not appear at the departure time, this capacity turns out as a loss opportunity for the airline; therefore, this situation could be directed by conducting overbooking policy. However, the occurrence probability of this case is very low when dealing with outbound logistics. It is most likely to be the subject of inbound transportation.

In conclusion, revenue and capacity management in the air cargo business stands as an open concept to improvements. By applying the right methods with an effective analysis of sector behaviour, companies can conduct higher profits under the same circumstances.

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