APPLICATION OF REVENUE MANAGEMENT PRINCIPLES IN WAREHOUSING OF A THIRD PARTY LOGISTICS FIRM

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Submitted to the Department of Industrial and Manufacturing Engineering
and the faculty of Graduate School of
Wichita State University
in partial fulfillment of
the requirements for the degree of
Master of Science

December 2007
APPLICATION OF REVENUE MANAGEMENT PRINCIPLES IN WAREHOUSING OF A THIRD PARTY LOGISTICS FIRM

I have examined the final copy of this thesis for form and content, and recommend that it be accepted in partial fulfillment of the requirement for the degree of Master of Science with a major in Industrial Engineering.

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Behnam Bahr, Committee Member
DEDICATION

To my parents and friends
I express my gratitude to all who have been constant support to finish my thesis. I am indebted to my advisor Dr. S. Hossein Cheraghi from Industrial Engineering Department whose suggestions and support especially at difficult times have been instrumental in finishing my thesis. I am thankful to him for the financial support for my studies in Wichita State University. I am also thankful to Prof Dr. Krishna K Krishnan for his valuable suggestions and support during my stint in Wichita State University. I extend my thanks to Prof Dr. Behnam Bahr for his time to review and suggestions to this thesis and Dr. Tao Yao from Pennsylvania State University for introducing me to revenue management fundamentals.

I want to thank my friends for the moral support and suggestions throughout my stint in Wichita State University. I am obliged to Thanh Do, Arun K Tatikonda, Govind Ramakrishna Pillai, Shyam Krishna, Vignesh Krishnamurthy, Vikram Minhas and Karthik Balakrishnan. Finally I would like to thank my parents for their understanding, moral support and love.
ABSTRACT

As global business landscape becomes more competitive, new and innovative methods to stay ahead of the competition are imperative. Profits being the bottom line of every business, margins are shrinking in the face of extreme competition. Overbooking is a revenue management concept that is used by the airlines to increase operating revenues. This study focuses on the application of this technique to the warehousing operation of a third party logistics firm with the objective of maximizing profit. It proposes a mathematical model to identify the overbooking limit to maximize profit. It shows the additional revenue generation potential of overbooking concept, in the warehousing operation of a third party logistics business. A discussion of the competition between different third party logistics businesses is also initiated.
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CHAPTER 1

INTRODUCTION

1.1 Overview

The rise of the global competitiveness in business is driving businesses to find innovative methods to stay competitive. As the profit margins become thin, companies have to find new ways to create profit to beat the competition. The science of revenue management consists of creative methods and practices to make better revenues and hence profits. Revenue management is necessarily “selling the right product to the right customer at the right price at the right time” (Talluri and van Ryzin, 2004). Revenue management deals with maximizing revenue for a fixed capacity of a product or service. It saves the capacity for the most valuable customer by proper capacity allocation, and constantly looks for the better revenue attaining opportunities.

Researchers have started looking at the applications of revenue management to the field of manufacturing from the start of the early 90’s, as more people realized the possibility of applying these principles to a manufacturing setting. In a manufacturing setting, these principles help to balance the demand and supply better. For the matter of fact, supply chain performance will improve by balancing demand and supply. Revenue management and supply chain management are complements of each other, and these principles address “all three categories of demand management decisions-structural, pricing and quantity decisions” (Talluri and van Ryzin, 2004).

According to yield management principles, revenues are controlled by price, quantity and structure based decisions. Price based decisions are based on segmenting the
demand class into price sensitive and price insensitive customers. Customers who need a product or service within a shorter response time will be ready to pay more and those who don’t worry too much about the response time are sensitive to the price at which the product is offered to them.

Quantity based decisions are based on whether to accept or to reject an offer, that is an order selection criteria based on the capacity available. Companies make the decision to accept or reject an order based on the profit from an order, i.e. it aims towards saving the capacity for high paying customers to make better profits.

Structure based decisions deal with market segmentation based decisions. One of the real world examples we can point towards structure based decisions is the make to order segment of dell computers, which segments its customers into different classes and different prices. In automotive segment of make to stock manufacturing, Ford has implemented revenue management techniques. Both of these implementations have been highly successful. This study researches the applicability of these principles to a supply chain.

Supply chain management is a key function of any organization. Supply chain consists of a group of elements such as suppliers, manufacturers, distributors, retailers and customers. The main purpose of a good supply chain is to satisfy the customers by providing competitive and lower costs. In order to accomplish this, logistics function in supply chain plays an important role. Distribution and warehousing is one of the key elements in this logistics network.

In this study, focus is on the warehousing operations of third party logistics firms, which provide supply chain management function. These firms come to picture when a
manufacturing firm doesn’t have the supply chain management function tied up to its operations. These firms have one of their functions as warehousing and distribution. They sell their floor space to multiple manufacturers or customers. In this situation, all the customers may not use the capacity to the limits allocated to them, i.e., if a certain percentage of warehouse space is bought by the customer of the warehouse and if he is not using the capacity then there is a revenue generation opportunity, by overbooking the capacity above a certain percentage of the available capacity of the warehouse space. A back up clearly needs to be arranged if all the customers plan to use their available capacity at the same time, which will incur a penalty cost. Also a significant amount of cancellations of the floor space orders can be possibly faced by the logistics provider, which can be dealt with a penalty as the customer is initiating the cancellation.

This capacity under utilization is dealt with applying overbooking techniques in revenue management. This implies that a certain percentage of booking above the available warehouse spaces is accepted. For this one needs to know, how much above the capacity he can book, so that he can maximize the revenue at minimum cost. This study is focused on finding a limit above which the capacity can be booked, so that one can obtain the additional revenue.

1.2 Research Focus and Objectives

Revenue Management as a science is increasingly gaining popularity in the field of manufacturing, in recent years. It involves pricing, structure and capacity based decisions to maximize the revenues and minimize the costs for a firm. These decisions on a systems perspective, increases the operational efficiency and profit for a firm.
Firstly, the research objective is to perform a state of art review of relevant literature in revenue management in manufacturing. The focus is to reveal the present state of research in this upcoming area and the future research directions.

Secondly, the research is focused on finding the revenue generation potential of overbooking concept in warehouses present in a supply chain. For a given capacity, the objective of the study is to reveal the additional revenue generation potential.

1.3 Thesis Organization

The thesis has been organized into five chapters. Chapter Two provides a state of art review of revenue management literature related to manufacturing and literature review of overbooking problem. The methodology is elaborated in the third chapter. The results and analysis of the model is described in the fourth chapter. The thesis concludes with conclusions and logical extensions of the work.
CHAPTER 2

BACKGROUND AND STATE OF ART LITERATURE REVIEW

Revenue management as a science has its origins in the airlines industry. Early 70’s saw some of the airlines offering higher class as well as discount fare, for the same airline. This was a practice adopted by the airlines to obtain additional revenue from the seats which would otherwise fly empty. This practice brought forth a problem of determining the amount of seats which should be protected for future full fare booking requests. If more than enough seats were protected for future full fare booking, then airline would depart with empty seats. On the other hand if sufficient seats were not protected, then airlines will lose full fare customers, which is similar to losing the opportunity to make additional revenues. It was clear that, for the development of effective control of the discount seats some kind of tracking of booking histories, enhanced information system capabilities and careful research and development of seat inventory control rules is needed. Littlewood (1972) of BOAC, presently British Airways, proposed that as long as the revenue value exceeded the expected revenue of future full fare booking, discount fare bookings should be accepted. This proposal marked the beginning of the science of revenue management.

2.1 Revenue Management Concept

Revenue management focuses on maximizing the revenues. Businesses face complicated selling decisions on a day to day basis. Traditionally, airlines faced a lot of everyday decisions including, whether to accept or reject the offer to buy, which segmentation mechanism should be used to differentiate among various classes of
customers, the terms of trade to offer, how the products should be bundled, how prices are to be set across various product categories, how to vary the prices over time, and how to allocate capacities to various segments of products (Talluri & van Ryzin, 2004). The above are some of the few decisions which the airlines have to make on an ongoing basis, to run their operations effectively.

Of the various decisions, which one of the decisions is most important and where, depends upon the context of the business, and the timeframe in which decisions are made. Strategic decisions like how to segment the market and how to bundle the products are taken relatively infrequently. Firms often have to commit themselves to certain level of price, by advertising the price in advance. Also they have to deploy certain capacity in advance. The use of capacity controls comes out of the fact that airlines sell various kinds of products using the same homogenous seat capacity. This gives tremendous control over quantity, and obviously quantity control is a naturally accepted way of control. Another major control is the price based control, where price across various product categories and price over time varies tactically, so that the airline gets optimum revenue from its business.

From the above discussion we can say that, there are mainly two major types of control used in revenue management practices namely price based revenue management and quantity based revenue management (Talluri and van Ryzin, 2004). Selecting one of these controls to be used varies across various firms within a particular industry and also depends upon situations. In the airline business, most of the major carriers commit to fixed prices and tactically allocate capacity, while low cost airline companies use price as their primary tactical control. Firms find innovative ways to increase their ability to make
quantity and price control decisions. Retailers hold back some percentage of their stock to make a mid season replenishment decision, rather than committing all their resources upfront. Some airlines dynamically allocate airplanes of different sizes assigned to particular flight depending on fluctuations in demand, rather than pre committing to a fixed flight size. Car rental companies now reallocate their fleet from one city to another depending on the fluctuations in demand level. All of these innovations help the implementation of quantity and price based revenue management.

2.2 Origins of Revenue Management

Following the airline deregulation act of 1978, the US Civil Aviation Board (CAB), loosened up its control over airline prices, which had been regulated earlier. With this, the established carriers were free to change the prices without the CAB approval. Large airlines went ahead with the introduction of computerized reservations systems (CRS) and global distribution systems (GDS). This helped to offer service in many more markets than was possible with the point to point service which existed previously. All these developments made the pricing and operations a complex process.

At the same point in time, new low cost airlines entered the market. Many of them, because of the low labor costs and simpler point to point operations, were able to profitably price than the major airlines. These developments made the airline travel quite elastic because of the low prices, driving the demand for airline travel. Potential for the low cost airline travel was noted with the rise of People Express which started its operations in 1981, had their costs 50-70% lowers than other major carriers. By 1984 its revenues rose to $1 billion, and its profits to $60 million, its highest profit ever (Cross,
1997). On the other hand, the major airlines had strengths which the new entrants lacked. They had more city pairs, frequent schedules and a brand and reputation name.

The impact of the low cost airlines was hitting the major airlines in terms of the net revenue. A strategy had to be devised to oppose the price war. In these times, American Airlines realized the fact that it can compete with low cost airlines price with its surplus seats, as its airlines have their seats at a marginal cost due to its fixed capital, wages and cost of the fuel. But to put this in practice American had to find some way of identifying its surplus seats in each flight. Also care had to be taken so that this is not at the cost of high paying business customers with some kind of switching restrictions so that the business customers won’t switch the seats to low cost products. American solved these problems through capacity controlled fares and purchase restrictions. In the capacity controlled fares they limited the number of discount seats. This provided a means for major airlines to fight on the price without losing business class customers. American Airlines Revenue Management practices generated around $ 1.4 billion in additional revenue over a period of three years starting 1988 (Smith et al, 1992). Due to this creative business model by American Airlines, Revenue management has become prevalent in today’s airline industry, and it is viewed as one of the key factors to run an airline industry profitably.

2.3 Overview of a Revenue Management System

A brief description of the generic operations, controls and design in a Revenue management system is given in this section. The process of revenue management involves 4 steps. They are data collection, estimation and forecasting, optimization, and control (Talluri and van Ryzin, 2004). Data collection involves collection and storage of
important historical data such as demand and causal factors so that data collected can help the analysis. Estimation and forecasting involves estimating the parameters of the demand model, forecasting demand based on the parameters estimated, and also to forecast other relevant quantities like no shows, cancellation rates. Optimization is finding optimal set of controls from various controls available, such as price, inventory allocation, and overbooking limits. Finally Control involves controlling the inventory sale using the optimized control, which can be carried out through firm’s own transaction system or it can be done through shared distribution systems (GDS).

The frequency in which these steps are performed is a function of volume of data, speed by which the business conditions change, type of forecasting, the optimization methods used and relative importance of resulting decisions.

2.4 A Conceptual Framework

Broadly speaking revenue management is a set of principles which can be employed across businesses where management of demand and technology is extremely important. Also a proper management culture should exist to carry out the implementation. To explain this, the study starts with the demand management process.

2.4.1 Multidimensional Nature of Demand

A firm demand can be characterized into multiple dimensions. This includes 1) The product it sells 2) The nature of the customer it serves, customer preference of products and their purchase behavior 3) the time factor

A value in this three dimensional space indicates a particular customers valuation for the product at a point of time. What revenue management essentially does is that, it
addresses the structural, price, timing and quantity decisions to exploit the potential in this multi dimensional demand landscape.

For instance, some revenue management problem situations fix the product and time dimension, and exploit the customer valuations for a single product at one point of time. In this they try to optimize the customer dimension of the problem. This is essentially what happens in auctions. The next group of problems deals with dynamic pricing of product to different type of customers over times, which is fixing the product dimension and vary the customer and time dimensions. There are problem situations which involve demand decisions of multi product over multiple time periods, where the customer dimension is not explicitly considered. The key thing is to methodically reduce the problem to implementable solutions (Talluri & van Ryzin, 2004).

To operationalize this science, the importance of information systems infrastructure cannot be over emphasized. We need computer systems to collect, store, and monitor and implement the real time decisions involved in the process. And in most industries it is possible to collect and store demand data and automate the demand decisions involved. The above discussion clearly emphasizes that demand models, forecasting methods and optimization algorithms combined with the modern technology of large databases, computers and internet had given an entirely new angle to decision making and have made the process of managing demand in a scale unthinkable by human means.

2.5 Revenue Management in Airlines

For completeness, we intend to begin the research by discussing the core concepts of airline revenue management. As discussed earlier the aim of revenue management is to
maximize the profits. Since most of the costs are fixed, it is required to focus on the booking policies to maximize the revenue. Consider the booking request of one or more flights arriving and departing within a specified booking class, at specific fare. “The fundamental revenue management decision is whether or not to accept or reject the booking”, (McGill and van Ryzin, 1999). Revenue management research in airlines falls in four key areas- forecasting, overbooking, seat inventory control and pricing. In this section we explain these key areas.

2.5.1 Forecasting

Forecasting is a vital element of a revenue management system. It is one of those important tasks which take the majority of development, implementation and maintenance time. At this point, it is worth to mention that, the forecast should not necessarily be seen as a single number, but it’s more complicated and need to be understood in statistical terms involving the inherent uncertainty in predicting future outcomes.

From an airline point of view, it determines the booking limit which has a direct impact on the revenues. Overbooking limit generally depends on the demand predictions. Predicting the demand situation and passenger behavior in airlines is a complicated issue. If we look at the price issue alone causing demand fluctuations, in 1989 itself there were about 30,000 reported daily price changes in US domestic airline industry alone (Williamson, 1992). Even though it is difficult to arrive at exact figures and numbers, good forecasting models are critical factors for these businesses.
2.5.2 Overbooking

Overbooking is an idea which is concerned with increasing the capacity utilization in a system if there is a possibility of cancellations. It is a measure to increase the total volume of sales in presence of cancellations, rather than trying to allocate the optimum customer mix. In terms of financial success, overbooking enjoys a significant position among all revenue management practices. The magnitude of the problem is revealed by the fact that, in airline industry 50% of the reservations result in cancellations, and about 15% of the seats go unsold without some kind of overbooking (Smith et al, 1992). This area has the longest history of research in airlines. Suggestions from Vickrey, a Nobel laureate economist, that overbooking conditions can be resolved by auctions, which pretty much dismissed by the airlines but proved to be prophetic later on. So this provides a pointer towards the importance of this area of the revenue management.

2.5.3 Seat Inventory Control

The concept of seat inventory control is based on the fact that, the available inventory can be utilized in the most optimal fashion, by saving the inventory for the future high paying customer. It deals with allocating seats among various fare classes of customers. Assuming we know the available capacity for allocation in a situation and the forecasted future demand for all the classes, seat inventory control problem deals with ‘accept’ or ‘reject’ decisions for a booking request in expectation that it can be sold to a future high paying customer. This has an important place in revenue management research as it helps to make some of the key decisions which can have a major impact on the revenue.
2.5.4 Pricing

Price is a significant to control product demand. Airline research on pricing looks at price as a control variable and explicitly models demand as a price dependent process. Varying prices is treated as the most natural mechanism in obtaining optimum revenue. Most of the retail firms use revenue management principles such as personal pricing, price negotiations such as request for quotes, price proposals, auctions etc to deal with uncertainty in product demand. Revenue management deals with the process of how to make these price changes. Firms often try to sell products at the highest possible price to their customers, at the same time acceptable to them. But more often to take the decision of which price is the most suitable one is rather a complex one. Recent times has seen a lot of software systems and pricing models assisting with the decision making process. Most of the pricing decision comes down to the fact that whether a firm is able to make the price changes in response to the market conditions. But this decision comes along with commitment that a firm makes in terms of price, flexibility of supplying products, and cost of making these price changes.

2.6 Revenue Management in Manufacturing

Revenue management as a science has immense potential in manufacturing. The strong association of revenue management to airlines has created myopia inside the field, as most of the practitioners and researchers see the principles in airline specific term which in turn hampers the research potential in other industries. Models in the airline industry reveal the fact that, the problem of unfulfilled capacity has stimulated a lot of research. Similar situation occurs in manufacturing industry, where unfulfilled capacity causes increased cost of production because of orders accumulating in peak load periods,
resulting in higher price of the product; which in turn results in losing the market captured by the product. This is one of the key motivations for research in this area. Also supply chain management (SCM), enterprise resource planning (ERP), and customer relationship management (CRM) are widespread practices where most manufacturers have huge amounts of data, and businesses are mostly automated. Added to this, most manufacturing firms have demand variability, customer heterogeneity and some kind of supply or production inflexibility. All the above reasons form a solid foundation for implementation of revenue management practices. As a pointer to this, Ford motor recently performed a revenue management technology implementation with proper information systems, in its pricing and capacity control areas.

To adopt the principles of airline to the manufacturing industry, it is important to identify the similarities of airline and the manufacturing industries. There should be a ground of commonality in the principles which can motivate further research. The similarities which exist between these two industries are that capacity is perishable, capacity in both cases are limited and cannot be easily changed, and demand is stochastic (Modarres & Nazemi, 2005). Besides this, manufacturing is increasingly becoming customer specific and flexible to meet customer’s specific expectations regarding product specifications. This implies that manufacturing companies are selling their capacity and manufacturability to the customers.

In this section of research we will look at the key reasons and trends which convince this line of research.
2.6.1 Capacity Management

Make to order companies (MTO) meet their demand by hedging against their capacity while make to stock firms (MTS) meet their demands by holding inventory on hand. So make to order firms need to manage their capacity to efficiently run their system.

The most critical problem which make to order (MTO) firms face is to utilize their capacity in the most optimum fashion to satisfy the demand in the system. The important thing to keep in mind in this context is that unused capacity is similar to lost revenue opportunity in airlines. When we take the case of companies having multiple products classes, the allocation of capacity is similar to order acceptance or refusal problem in revenue management. The acceptance or refusal is based on maximizing profit potential of the capacity which is scarce, by accepting only the most profitable order.

This infers that revenue management is the science of selling the right capacity or inventory to the right customer, at the right price and time.

2.6.2 Market Segmentation

In a general market for products, the customers can be segmented into different groups based on their willingness to pay different prices for the same product. One class of customers who want to pay less but they are willing to wait longer i.e. this class of customers are tolerant to longer lead times. The other class of customer need shorter lead times and better service, at the same time they are willing to pay the extra money for that. This indicates a revenue attaining opportunity by introducing some kind of segmentation of the customers a business have. The car manufacturing industry has multiple pricing
structures to attract different types of customers even though it is not that pronounced. The various possibilities of market segmentation are, varying lead times (shorter lead times at higher cost), variation in after sales warranty, different cancellation policies for different classes of customers, higher flexibility allowed for high priced segments (Modarres & Nazemi, 2005).

2.6.3 Pricing in Manufacturing

Pricing is the most obvious technique to balance the sales revenue of a firm. It helps in optimizing the revenue by the introduction of a higher price when the sales is good and keeps the business afloat by lowering the price when sales is not good. One of the key concepts of yield management is capacity perish ability. As in the case of airlines this is obvious that once a seat is left empty after the airline departs, the opportunity to make the revenue is lost forever. But in the case of manufacturing the products built and stored can be sold later. But the prevalence of high competition in industry forces the perspective to view capacity as perishable. We take the example of a car manufacturing business. Even though cars can be produced and stored in completed inventory, if we are not able to sell a car in a competitive market and our competitor achieves the sale, then it can be viewed as a lost revenue making opportunity.

Airline business offers a large number of fares for the same market of customers, which results in charging different fares for the same seat. This is achieved by some kind of fencing for the fares like 30 day advance reservations to give discounts. The same situation applies for manufacturing where cost sensitive customers will allow a reasonable period of time before the date of delivery of the final product. And most of the
times this kind of pricing are achieved by some kind of segmentation of the market of potential customers.

In the section ahead an attempt is made to conduct a comprehensive survey of revenue management literature relevant to manufacturing.

2.7 State of Art Review of Revenue Management in Manufacturing

The principles of revenue management have been prevalently used in service oriented industries. It has been a recent practice to look from a manufacturing perspective. The body of research related to manufacturing revenue management is very much in the nascent stages of its development. But the good thing is that researchers have started to look at the opportunity of extending the revenue management principles beyond airlines. There have been a lot of industry adopters beyond airlines, such as retailing, car rental companies, manufacturing, cruise ship lines, energy sector, theaters, sporting venues and broadcasting to name a few. In this section of research, we will conduct a state of art survey of the literature available presently related to revenue management in manufacturing. Since the original principles of research comes from airlines, we will survey the research literature relevant to airlines from which the manufacturing research body is extended, and conduct a thorough survey of present state of research in manufacturing.

For completeness of the survey all the published articles, conference proceedings and also the working papers will be included. The investigation in this section has tried to bring out the current state of research in this area. But no claim is made to have identified all the revenue management publications and regret any omissions.
2.7.1 General Revenue Management Review Literature

Weatherford and Bodily (1992) provides a general categorization of perishable asset management problems. They classified the published work in revenue management problems at that time. Also they introduced a general taxonomy for the revenue management literature. The term “Perishable asset revenue management (PARM)” for the general class of inventory control problems is introduced into the literature by their research.

The general revenue management literature is discussed in (vanRyzin & McGill, 1999). This research has been a comprehensive survey of revenue management literature in airlines revenue management. It gives insight into the revenue management research areas and the classification. The classifications which have been discussed in this research are forecasting, overbooking, inventory control and pricing and it reviews the models developed under these classifications, and gives a complete picture of the current state of research and future directions of research in revenue management in airlines.

Table 2.1: General Revenue Management Review Literature

<table>
<thead>
<tr>
<th>Reference</th>
<th>Abstracts</th>
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<tbody>
<tr>
<td>Weatherford and Bodily (1992)</td>
<td>Classifies the published work in revenue management and proposes taxonomy for the RM literature.</td>
</tr>
<tr>
<td>McGill and van Ryzin (1999)</td>
<td>Does a complete review of RM literature at that point. Also classifies the entire body of literature available in transportation revenue management into forecasting, overbooking, and inventory control and pricing. They proposed a glossary of RM terminology to the literature.</td>
</tr>
<tr>
<td>Author(s)</td>
<td>Summary</td>
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<tr>
<td>Pak et al. (2002)</td>
<td>Does a review of the operations research techniques to solve airline RM problems.</td>
</tr>
<tr>
<td>Bitran et al. (2002)</td>
<td>Reviews the literature on dynamic pricing literature related to RM problems.</td>
</tr>
<tr>
<td>Elmaghraby and Keskinocak (2003)</td>
<td>Reviews the dynamic pricing literature with the focus on inventory considerations.</td>
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</table>

Pak et al. (2002) and Bitran et al. (2002) also give a review of Operation Research techniques for airline revenue management problems. Bitran et al. (2002), in particular, gives an overview of the pricing policies and its relation to revenue management. They have reviewed the general pricing literature related to revenue management and presented the main results, practical implications and insight into the future research opportunities which exist in pricing area related to revenue management.

Elmaghraby and Keskinocak (2003) review the literature on dynamic pricing in the presence of inventory considerations. They have pointed out that there has been an increasing interest on the adoption of dynamic pricing in industry. The reasons that they have observed for this are increased demand availability data, easy price changing possibility due to new technologies, and the presence of decision support tools for analyzing demand data and prices.

### 2.7.2 Revenue Management Literature with Focus on Manufacturing

Manufacturing operations can be classified according to two disciplines: Make to order (MTO) and Make to stock (MTS). There is a reasonable difference in the way
which orders are processed in these two systems. The distinction between these two systems is discussed in Caldentey et al (2002). They worked on the problem of optimal order admission policies in the electronic market places, to select the most optimal long term contract and optimal production schedule to maximize revenues.

In make to stock manufacturing (MTS) environment, there are several researchers dealing with the problem of allocating the scarce inventory among competing class of customers. Cohen (1977) is one of the few initial researches in this direction. In service operations management area this subject has been studied by a variety of researchers, which is similar to the problem of competing classes of demand in airlines by Kimes (1989), in the hotel industry by Relihan (1989), and in rental car agency cases by Carrol and Grimes (1995). These researches focus on the problem of allocating the resource to the most valuable customer.

In this study, the body of research related to manufacturing is performed broadly into three major classifications pricing, structure (market segmentation) and quantity (order selection) (Talluri & vanRyzin, 2004). In the sections ahead review of the literature under these classifications is performed.

### 2.7.3 Pricing

Pricing is most important element in a manufacturing revenue management. In fact pricing is the most researched area in manufacturing revenue management. Most of the research efforts have concentrated on how to vary the price in order to maximize revenues. One fact which is worth taking into account is that, there is an increasing interest shown by industry to implement pricing practices. One of the noted implementations in industry was from Ford motors. Ford is reported to be carrying out a
high profile pricing software implementation deal with variation in pricing of its products.

To look at the overview of the pricing literature in manufacturing, the pricing systems are classified under make to stock (MTS) and make to order (MTO) manufacturing. Most of the current research in pricing is focused on make to order (MTO) systems because the pricing principles are more applicable to these systems. The review will start with make to stock (MTS) systems and proceed to make to order (MTO) systems pricing.

2.7.3.1 Pricing in Make to Stock (MTS) Manufacturing

Gayon et al (2004) have studied the potential benefits of dynamic pricing in a controlled production environment where demand is fluctuating. In this research the potential customer demand is generated by a Markov Modulated Poisson process, but the actual demand does depend on the prices offered at the time of transaction. The results for optimal pricing and replenishment policies are obtained. The results indicate that the pricing and production should depend on the current demand environment and dynamic pricing is more optimal in a fluctuating demand environment.

Extending this research Gayon & Dallery (2006) studied the impact of pricing on a partially uncontrolled production environment. They also considered a make to stock (MTS) production system which serves a market of price sensitive users. The system considered in their study is a production process, where a decision maker controls the production occurring in a single production facility and system under consideration is modeled as a make to stock queue with lost sales. The research addresses the problem of potential benefits of dynamic pricing over static pricing with the objective of maximizing
the profits. As the result of the study, they have shown that the impact of dynamic pricing in generating better profits over static pricing is more pronounced in a partially uncontrolled production environment.

Caldentey & Wein (2006) in their study considered a make to stock manufacturing system. The considered system was that of an electronic market which had two selling channels, namely long term contract and spot market. From the very beginning a risk-averse manufacturer will choose a long term contract while buyers may choose either one of the two channels. The manufacturer’s problem is to accept or reject orders such that he obtains a long term optimal contract price, production schedule and admission policy to maximize revenues minus inventory, holding and backorder cost. In the study they have shown that, segregating the orders and accepting the high priced ones by the proposed order acceptance policy helped the system to get higher profits than the random acceptance of orders.

There is another branch of research in make to stock (MTS) which studies the impact of competition. Adida & Perakis (2005) addressed the competition problem in a make to stock manufacturing system when firms compete on the basis of dynamic pricing and inventory control. They considered a multi product capacitated dynamic setting where demand is a linear function of the price of the supplier and the firm’s competitor.

Extending their line of research Adida & Perakis (2005) investigated a dynamic pricing and inventory control problem in a make to stock manufacturing system. The focus of the research has been to come up with an optimization formulation for a situation where the demand is uncertain. The system under consideration is a demand based fluid model system where inventory cost is linear and demand is a linear function
of price. The study formulated the problem as a deterministic one. The research claims that the fluid model is similar to a real one. As a result of investigation they came up with an optimization approach to incorporate demand uncertainty in a dynamic pricing problem.

2.7.3.2 Pricing in Make to Order (MTO) Manufacturing

Pricing principles in revenue management is more applicable to a make to order (MTO) manufacturing system. This can be noted from the fact that the concentration of research occurring in make to order manufacturing revenue management is very high. In this section, an up to date survey is carried out on the current literature in make to stock pricing systems. A chronological order has been followed to review the works on pricing in MTO systems related to manufacturing revenue management.

To our knowledge, the first noted literature on pricing related to manufacturing revenue management is vanRyzin & Gallego (1994). Their motivation for research was the fact that across the industries managers facing the problem of selling the inventory within the deadline. The problem which they studied was pricing the inventory dynamically, when demand is price sensitive and stochastic and the firms have the sole objective of maximizing the revenues. They have found the upper bound of revenues for a particular class of demand. They also extended this result to the case where demand is Poisson and the case where demand rate is varying.

Feng & Xiao (2000) investigates a similar situation where the attempt has been to come up with a continuous time yield management model. For this the have considered a system where demand is a Poisson level process, discrete price levels offered to perishable assets, and management takes control of the adjusting the price levels as sales
evolve. The model is formulated as an intensity control model and the optimal solution in closed form has been obtained. The observation is that when prices follow a concave envelope, it is a potential optimum. The author’s claim that their results are superior compared to the previous research by vanRyzin & Gallego (1994) as they obtain the exact solution compared to a deterministic heuristic in previous research. They also claim that optimal solution is easy to compute using their model.

Morris (2001) pointed towards a trend of benefits obtained by using dynamic pricing in real life markets. As the make to order markets grow in size, there is a growing need to automate the process of pricing, which challenges the seller’s knowledge of pricing strategies. The research designs a simulator which analyses a pricing strategy, where a seller has a finite time horizon to sell his inventory. Through the analysis of various price results, it demonstrates that the simulator can be used as an effective tool for employing the pricing strategy. The research claims that the simulation based technique can be used for implementation of dynamic pricing strategies in real life markets.

Swann (2001) investigated pricing strategies to improve the supply chain performance. It points out that many industries have started using innovative pricing techniques to improve their capacity utilization and better inventory control. This work claims that the coordination of production and pricing decisions have scope to improve supply chain performance by better management of demand and supply. The research studied a system where pricing and production decisions are taken in a multi period horizon, developed and analyzed various planning strategies and generated computational results to provide various managerial insights. The result of the study claims that, profit
from dynamic pricing is significant, dynamic pricing can be used as a significant tool to absorb the demand variability in supply chains and significant profits can be attained by a few price changes. Another interesting result of the study has been the claim that price changes can be as high as 10% of the fixed price.

Monahan et al (2002), studies the pricing problem from a news vendor’s perspective. They studied the setting in which selling prices to be determined in an environment where demand is random and supply of the product is fixed. They developed a dynamic optimization model, where dynamic pricing problem formulated similar to a newsvendor problem. This study leads to insights into profits and actions of a price setting newsvendor. The research claims to develop an optimal pricing strategy over a finite horizon. Also the study analyzed how the market parameters affect the optimal solution through a set of numerical experiments.

Following this research, Dasci (2003) developed a two period model to analyze the effect of variable pricing on profits, considering the impact of competition. The research studied the setting of two periods, where the firms announce their prices and observe the sales in respective periods. The result of this study shows that even when there is no uncertainty in demand and consumer behavior, dynamic pricing exists. In addition to this, the study has shown that inventory control has both positive and negative impacts on the firm.

As the interest for the variable pricing gained interest both in industry and academic literature, researchers started looking at the scope of decision support systems in pricing implementation. Montgomery (2003) conducted an attempt in developing a pricing decision support system, which takes into account the demand and the variation in
demand due to consumer response to prices. The study made an observation that the recent advances in academic literature will help in the implementation of pricing based decision systems. Also it claims that these systems have the potential to alter the way prices to be set in future and type of data collected from the market.

Another stream of literature worth noting at this setting is the studies which look at the internet as a medium for realization of variable pricing. These literatures are important from the perspective that, price changes are instant according to fluctuations in supply and demand, and internet is a reliable and fast medium to implement this. Jayaraman & Baker (2003) investigated the impact of internet as an enabler medium for dynamic pricing. The study explored the possibility of auctions, reverse auctions, exchanges and negotiations. It throws insight into virtually unexplored options for companies to make profits. The study observed that internet is the most powerful tool to obtain instantaneous consumer response and the possibilities of e-commerce portals based on pricing in the future. Added to this, it studied the different methods of demand data collection over the internet.

Maglaras & Zeevi (2004) designed an innovative model of service system with the aim of maximizing revenues. The study defined the system as two different types of service- first type of service is a Guaranteed class (G) and the second type is Best effort class (B). In this system the users are sensitive to both price and congestion occurring in the system. Design variables are such that the residual capacity not used by G class is allocated to B class of consumers and there will be a mechanism which informs the users about the state of congestion in the system. For the proposed system a pricing rules for the two classes of customers is derived. The claims made in this research are that pricing
rules are “almost” optimal and notifying real time congestion effects have increased the revenues.

Xu & Hopp (2004) studied the value of demand learning in a system with simultaneous inventory replenishment and demand learning. The system considered has one time inventory replenishment and employs dynamic pricing. Customer arrivals to the system are partially deterministic and the arrival process cannot be represented strategically. The study observed that demand is deterministic when learning is not taken in to account and demand function is stochastic when learning is taken into account. The important result of the research is that, it brings out the significance of the learning process in demand prediction of the inventory and the corresponding pricing, which can have a significant impact of the firm’s revenues.

Another line of research in the pricing literature argues that price changes cannot be made intermittently. Netessine (2004) considers the problem of variable pricing of a product by a monopolist. The study argued that even though it looks attractive for companies to vary the prices when demand cycles vary, varying prices has high costs associated with it. Instead they proposed a piecewise constant pricing policy, to limit the price adjustments. The study considered the system where there is limited number of price changes, where demand depends on the current price changes, and capacity set ahead of the selling season. They showed that optimal time of price changes and proper capacity allocation is critical for optimal profits.

The impact of competition in pricing is a significant area of consideration. Most of the price changes in businesses are driven by competition. Perakis and Sood (2004) studied the multiperiod pricing for products in an oligopolistic (competitive) market.
the system considered the inventory at the beginning of the horizon remains constant as there is no option for production between the intervals. The research studied the convergence results of the algorithm, which helps to compute the equilibrium policies. The study claims that their model helps to implement pricing strategies effectively in a market driven by competition.

Aggarwal et al (2004) pointed to the possibility of using consumer profiles available due to advances in the information age, for obtaining better revenue. The study proposes to strategically set prices to different products after taking into account, the customer choices. For this, the research studied a multi product pricing problem where the customers like the products, their budgets is taken into consideration, with the objective of setting the prices such that the overall revenue of the company is maximized. They came up with approximation algorithms after modeling different purchasing patterns and market assumptions. The claim is that using consumer profiles and their choices while setting the prices can lead to more revenues and profit to the manufacturer.

Another direction of research is the linking of pricing and operational decisions. Fleischmann et al (2004) investigated the relation between pricing and operations. They made the observation in their study that as more companies understand the dynamics of pricing and its impact on supply chain, it can directly improve the operations of the firm. This is due to the fact that relationships between supply chain partners and operations of a firm are closely related. The important result of this study is the relationship they have observed between pricing and operations, because this naturally concludes that dynamic pricing has a positive impact on the manufacturing operations. This opens up a relatively
less explored area research area of research in manufacturing operations employing dynamic pricing techniques.

Biller & Swann (2005) performed a similar research of pricing decisions influencing the operations of a firm. They investigated a problem where pricing helped to attain the operational standard, which otherwise would be difficult to achieve. The problem which they studied was the emission enforcement standard in automotive industry for a fleet of vehicles related to a company. If these standards of regulation fall outside the customer preferences and technology fails to deliver, manufacturers use price as a tool to achieve the operational standard. This denoted a trend of manufacturing firm’s view on pricing and its increasing influence to use it in operational decisions.

A similar research in the operations direction was by Celik & Maglaras (2005). They studied a make to order system that produces multiple products to a market where the users are time sensitive. The research has pointed to the fact that for optimizing the operations of the firm it has to optimize the lead time, pricing, and sequencing decisions. The study proposes the combined use of pricing and lead time quotations to optimize the long term revenue and profits of the firm. It modeled the problem as diffusion control problem that obtains optimal pricing, lead time and sequencing policies and provides insights to practically implementable recommendations. They have claimed that the model provides a near optimal solution.

As the acceptance of pricing as a standard for operational decisions increased in academic literature, the applicability of models developed for the calculation of dynamic pricing for industry applications was logically the next line of research. One of the notable literatures in this direction is by Narahari et al (2005). Dynamic pricing is
calculated on the basis of models which are applicable to the situation. The study surveyed different models used in dynamic pricing and discussed the situations under which each model is likely to succeed. Also the study discusses the role of these models in dynamic pricing and the importance of using proper models to employ pricing. It has also discussed the significance of learning factor in dynamic pricing models.

Caldentey & Araman (2005) introduced the learning factor in the setting of dynamic pricing. For this the study has considered two cases: In the first case the entire stock has to sell out within a particular period. In the second case, the seller can stop selling the product at any time to switch to a different strategy. The study assumes that price change occurs according to certain market parameters, and they allow a change of strategy as the seller learns the price factor. The study also proposed a pricing policy and a stopping rule depending on the inventory position of the seller.

Consumer behavior is one the key factors which influences the prices. So considering the customer behavior as a factor in deriving a pricing strategy is critical for the completeness of the model. Bitran et al (2005) studied the impact of consumer behavior on demand and pricing. The study considers that a stream of potential buyers arrive at the system stochastically. At each demand interval the consumer arrives at a system, observes the prices and he may or may not make the purchase. In this research they capture the customer behavior on the prices of system at each state, where the prices are driving the demand. As a result the study has proposed an optimal pricing policy after considering the consumers purchasing behavior for a particular price.

Consumer behavior generates a change in the demand, and the often perceived demand variation is the case where demand varies as a time varying function of price.
Along the similar lines, Chou & Parlar (2005) considers a basic revenue management problem on a system where demand for a product varies as a time varying function of price in a linear fashion. For the system considered the study assumes that a fixed amount of inventory is available in the beginning. The research investigated the problem to determine the optimal price for such a system to generate maximum revenues. The case where the initial inventory can be a decision variable is also considered. For the defined problem they derive optimal price and inventory levels to maximize the revenues. As an extension to the problem, they derive the result for the case of dual products.

Su (2006) considered the pricing with the viewpoint of strategic customer behavior. For this the study considered a system where the monopolist sells inventory over a finite horizon. In this system the seller varies the prices as the customers come into the system in a continuous manner. At each point customers can exercise three different options: to buy the product at the current price, to exit, or to stay in the market to buy later. Each and every customer has different valuations for the product at the same point of time and different degree of patience. In this study the author has proposed different strategies for different customers. The result claims that these strategies can lead to better revenues and profits for the firm.

Another interesting line of research in pricing is the joint consideration of pricing and inventory, to find out the optimal levels of pricing and inventory so as to maximize the profits. Aydin & Porteus (2005) conducted an investigation on a system where the model of demand involves multiplicative uncertainty. They showed that as the competition increases the price of the product goes down, and as quality of product
increases the price also increases. The study claims that their model gives the optimal prices under a given inventory condition, as compared to other available models.

With the acceptance of effective pricing strategies gaining acceptance in academic literature, more advanced models and concepts started appearing in academic literature. Maglaras (2006) studied a more specific revenue management problem. In his investigation a multi class queue with controllable arrival rates, linear holding cost and general demand curve system was considered. For this system a revenue maximization problem was studied with a selection of a pair of dynamic pricing and sequencing policies. For the proposed pricing and sequencing policy gave numerical results which show that dynamic pricing is beneficial. They also claim certain insights as part of the study, like, invest in scarce capacity, pricing and sequencing decisions are coupled, and pricing decisions lead to work load maximization.

Lin (2006) studied the impact of learning in dynamic pricing. This research focused on the specific issue where the firm does not possess the accurate demand forecast. Rather it uses the real time sales data to calculate the arrival rate information. With this information the firm can come up with the future demand forecast more accurately, and use that forecast to dynamically vary the prices for maximizing the revenues. The author points out that for most of the industries real time demand data can be a more accurate estimate of future forecast, than using the historical demand data. So one of the key assumptions of the research has been that only the seller can estimate the customer arrival rate and hence the future forecast should depend on that data. The research claims that the model is optimal and it is also robust when the true customer
arrival rate is different from the original demand forecast. It also claims that this model can yield most optimal results for retailing industry.

Finally to get the most current state of pricing practices, a discussion is carried out from the conference held at Georgia Institute of Technology. Garrow et al (2006) discusses the key directions from the conference across manufacturing and its impact on the supply chain and across other industries. It clearly follows that pricing has a long term impact due to influence of internet and e-commerce. The proceedings clearly say that the future integration opportunities existing in the supply chain is immense. The use of pricing as a key factor to balance the demand and supply across various industries is clearly visible.

The section ahead will discuss the quantity decisions classification, which is the second major classification in revenue management in manufacturing.

2.7.4. Quantity Decisions

Quantity decisions involves that whether one should

- Accept or reject an offer to buy a product or service,
- Allocation of capacity to different segments and channels,
- When to withhold a product from selling in the market and
- When to resume selling at a later point (Talluri & vanRyzin, 2005).

Most of the revenue management decisions in manufacturing are quantity related decisions. It involves efficient use of the production facility to maximize the benefit of the manufacturer. Effective use of facility to optimum levels from revenue management perspective involves taking key decisions like, how to use the available capacity in the facility, whether the capacity available uses it for the most valuable customer. Effective
execution of these operational level decisions will help a manufacturing facility to fare better than the traditional management of the facility.

In congruence with its importance, most of the research in revenue management in manufacturing is occurring in quantity decision related areas. Quantity related decisions literature is further classified into order selection and capacity allocation decisions.

2.7.4.1 Order Selection

Order selection decisions involve selection (accept / reject) of an offer to buy the product or capacity in a manufacturing environment. The goal is to accept those orders which are going to maximize the benefit to the facility and reject the rest of them i.e. basically serve the higher end customers and accept the lower end customers only if there is capacity left in the facility.

To the best of our knowledge, the first occurrence of order acceptance/ rejection problem occurred in research literature in Carr & Duenyas (1999). Their research is motivated by their observation of the fact that, suppliers in many industries accepting orders from a large manufacturer to supply them the product and then take additional orders on a make to order basis with other sources i.e. this phenomenon indicates the suppliers prioritizing the order. They characterized the problem as sequencing and admission control problem in a production system with two classes of products, the first one is a made to stock where the firm is committed to deliver the product, and the second one is made to order class of products where the firm is free to accept or reject the order. The problem is to find out how the firms decide whether to accept or reject the order. They derive a policy of how to make to decision for a single server queue.
A problem along similar lines was investigated by Kuhn & Defregger (2003). They carried out the study with the aim of exploring the possibility of applying revenue management principles to manufacturing. For this end they considered a make to order manufacturing company, which receives orders of different processing times, due dates and profit margins. The problem for the manufacturing facility is whether to accept or reject the incoming order. It is presented as a markov decision problem model. To solve the problem they came up with a heuristic and evaluated the case using numerical results. The heuristic helps to select which incoming order to be rejected and which one to be accepted so that the facility ends up on higher side of the profit margins.

Another class of order selection problem focuses on problems in lead time flexibility and its benefits, which a manufacturer uses it to their advantage. Keskinocak et al (2003) investigated the problem of order selection when the manufacturer possesses the flexibility to choose his lead time. The focus of the research is to come up with a mechanism to coordinate lead time and order selection and to find out under what lead time flexibility the manufacturer attains maximum profit levels. By numerical analyses they showed the benefits of lead time flexibility in different demand environments and in situations where there is seasonality of demand. For discussion of the results they considered the situation where manufacturer who has and does not have the capability to deliver the orders before the time they have committed for the delivery.

Gallien et al (2004) discusses a framework for negotiating along lead time, price and quantity. They worked on the problem of dynamic admission control of jobs into a single machine with preemptive scheduling. They use the concept of minimum workload function to establish that early due date scheduling can be assumed with no cost to
They proposed a discrete time formulation with the aim of maximizing long term profits. Also they derived two heuristic policies and shown with the computational results that the proposed formulation is better than early due date scheduling to gain profits.

Kuhn & Defregger (2007) investigated order selection problem from perspective of inventory capacity. The situation considered is the revenue management of a make to order company with limited inventory capacity. In the system, orders arrive stochastically over an infinite time horizon, with different profit margins. The decision is whether to accept or reject the order. The problem it is formulated as a markov decision process and is solved with a heuristic procedure. The numerical results show that considering the problem as revenue management yields better results than the First Come First Serve (FCFS) policy.

Another interesting research direction in order selection is where the firm selects the orders, and implements this order selection procedure into its production facility based on which order is advantageous to the firm. Geunes et al (2006) developed a planning model which decides which orders to select, on the basis of price which sets the firms demand level priority to that order. Previous research in this direction assumes that a particular firm knows its demand level before the production starts. But under the current setting the firm selects the orders which are advantageous to it and implements those orders into the production schedule so that it produces only the most profitable ones. They claim that their model integrates the pricing and production planning to obtain optimal revenues and profits to the manufacturing facility.
2.7.4.2. Capacity Allocation

The most important resource of a manufacturing firm is capacity. Effective management of capacity is the prime objective of a facility to optimize its outcomes. Capacity allocation principle in revenue management involves allocating the available capacity to the most valuable customer. The idea is to allocate the capacity to lower end customer only if there is capacity left after the serving the high end customer.

Harris & Pinder (1995) were the first to investigate along these lines. They considered an Assemble to Order (ATO) system and proposed pricing strategies and stop sales tactics to optimally allocate the pre-existing capacity. They also pointed that the increasing importance of customer responsiveness will increase the relevance of revenue management in a make to order environment. They proposed a relatively simple mathematical model framework to accept higher end orders and reject others and claim that using this concept will yield better revenues. The important contribution of this work is the theoretical framework it provides for future research.

Kapuscinski & Tayur (2000) studied the basic discrete time model of capacity reservation in a make to order environment for two different classes of customers, with a stochastic demand. The specific assumption made in their model is that, different class of customers are penalized in different margins for their quoted lead times. They derived an optimal policy for the capacity reservation problem and developed an approximation which yields near optimal solutions quickly. They showed that this heuristic performs well than the available heuristics for the problem. The sole aim of the manufacturer is to allocate the available capacity to the most profitable one and reject the capacity in anticipation of future orders.
Feng & Xiao (2000) investigated the case where finite products are sold to two different markets at their respective prices. Certain products are reserved for higher end customers. To manage the revenues better, management some times may decide to stop serving the lower end customers. In their study they derived an optimal stopping time, which is best time to arrive at a decision, when to stop selling one class and serve the other class for better revenues.

Roundy et al (2001) worked on the order selection problem from the capacity allocation angle. For this they considered a setting where a manufacturer of automotive parts which produces a wide variety of parts with significant set up values. The manufacturer has to quickly come to a decision whether to accept the order or reject the order after considering its capacity. In the research they derived an order acceptance problem with a consideration for their capacity. They treated the problem as an NP hard problem and noted that three of the heuristics-genetic algorithm, simulation annealing, and a linear programming based heuristic for the problem looks promising. But they noted the limitation of the formulation that for the formulation time is treated as a discrete variable. One future direction of research pointed out is to extend the formulation to handle greater number of time periods or to treat the problem in continuous time periods.

Recent research along these directions focuses on considering both capacity allocation and pricing on a simultaneous basis to maximize the revenues. Feng & Xiao (2006) integrated the pricing and capacity decisions. They considered a system where a supplier faces a decision as of what prices to sell its products to different micro markets. Also the study identified the need to consider the market where customer is active. For
this system they have proposed a continuous time model which integrates pricing and capacity decisions. This is based on the assumption that at any given time the supplier has to make two decisions of the customer class it has to serve at which particular price. They have claimed that this control is easy to implement and give optimal revenues.

Another research along the similar lines to integrate pricing and capacity decisions is by Maglaras and Meissner (2006). They considered a system which has a fixed capacity and produces multiple products. The system tries to maximize its profit over a horizon by employing capacity allocation or pricing strategy. Also they came up with several static and dynamic pricing heuristics. They developed heuristics for pricing and capacity controls for multiple product environments and validated using numerical results. They claim that the heuristic achieves optimal performance.

Jin & Wu (2006) modeled the capacity reservation in the electronics industry where the degree of perishability of products and capacity is highly driven by the innovations occurring in the industry. This produces demand volatility where reservation of capacity can act as a risk sharing mechanism. In this model the customer reserves a future capacity of the facility at a cost. In this highly volatile demand sector this is important as capacity reservation is more advantageous to the manufacturer than the customer. In their investigation they considered a one customer, one manufacturer system with a stochastic demand. They have extended this to ‘n’ customer case. They have discussed the similarities and differences between capacity reservation and other supply chain contracts. Even though they claim that this will prove advantageous to the manufacturer in the midst of high perishability electronic markets, there is a need of more solid framework before these concepts can be implemented.
The section ahead will discuss the structural decisions, which is the third major classification in revenue management in manufacturing.

2.7.5. Structural Decisions

Structural decisions involves segmentation and differentiation mechanisms, selling format used (auctions, negotiations), terms of trade offered (includes volume of discount, cancellation or refund options) (Talluri and vanRyzin, 2005)

Segmentation of customers has been a successful strategy for companies in achieving optimum revenues. At this instance, the strategy employed by Dell computers is worth noting. Dell segments its customers into different classes (educational, home, small business, medium and large end business customers). Also, Dell employs differential pricing and service strategy for these classes of customers. This business model employed has been tremendously successful in highly competitive assemble to order (ATO) personal computer market. This brings out the possible benefits of segmentation of customers and the trend in the industry where the International Business Machines (IBM) and Hewlett Packard (HP) are about to follow the same model of segmentation like Dell. All these developments throw some insights into the future business models. The academic literature in this direction is pretty much in the early stage of development and the amount of research literature is relatively few compared to pricing. In this section an up to date review of the available literature will be conducted, which will provide a clear picture of the current state of research in this direction and also gives insight into future research directions. The review of the literature will be carried out chronologically.
To our knowledge the first occurrence of literature in this direction is by Biller et al (2005). They investigated the importance of direct to customer model of business and segmentation of customers to improve the long term supply chain performance. They have proposed that a direct to customer model coupled with dynamic pricing strategy can be a productive way for the manufacturing companies to face the competition. For this research they have considered a system which incorporates pricing and inventory control under different capacity limits in a multi period horizon. They showed that this strategy of dynamic pricing generates beneficial results. Also they extended the study to multi product situation.

A key research in customer segmentation along the similar lines as previous research was by Kocabiyikoglu & Popescu (2005). They studied the impact of customer segmentation in a system where demand is stochastic and price dependent. This has been a significant investigation as the model they considered is closer to a real world situation. They showed that a joint strategy of dynamic pricing and protection level for higher end customer leads to better profit benefits. They claimed that the results are relevant to flexible manufacturing systems and single product newsvendor model. The significant contribution from this research is that the results of pricing and availability optimization are carried out in a model which is more realistic, which provides stimulus for future research and practices in customer segmentation models.

Another research in this similar direction is by Raju et al (2006). In this they investigated the impact of ‘learning’ to calculate reorder level, in a system where dynamic pricing is practiced. For the system considered there are two segments of customers. One class is called ‘captives’ and the second class as ‘shoppers’. Captives are
the loyal customers who are mature, while shoppers are the class of customers who are
carried away by the promotions and discounts. The seller is the learning agent in the
whole system and uses learning to arrive at optimal prices, which will optimize the
seller’s metric of performance. They claim that their model will help to compute optimal
reorder point and quantity to arrive at an optimal inventory policy. They also claim that
this is an optimal model for calculation of dynamic pricing for electronic products and in
the calculation of volume discounts.

A different stream of literature in customer segmentation is where firms try to
obtain optimal inventory policy and production schedule on the basis of segmentation.
Duran et al (2006) considered a two customer class problem where the first one has more
priority for service than the second one, where demand and production are stochastic
functions. For such a system they tried to develop an optimal inventory and production
strategy which takes capacity limitation into account. They employed a priority
differentiation strategy for the different class of customers and derived optimal threshold
values for inventory and production. By computational analysis they showed that the
differentiation strategy yields a better profit than a traditional policy.

Another interesting research in similar lines as above is by Benjaafar & Elhafsi
(2006). In this study they have considered a system with m components, n customer
classes and one end component. All the previous research studied only a two class of
customer problem. They formulate the problem as a markovian decision process and
derive an optimal policy for production and inventory levels. They claim that deriving the
optimal policy on the basis of the decision policy yields better results than the normal
policy levels for inventory and production. The important contribution of this investigation has been the results obtained for ‘n’ customer class which is more realistic.

2.7.6. Auctions

Structural decisions in revenue management involves selecting the form in which selling is carried out. The impact of internet in commerce is driving a new form of selling, in the form of auctions.

Caldentey & Vulcano (2006) considers a system where the seller faces Poisson arrival of customers in an online auction unit. As every customer has equal option of buying the product and trying to maximize his gains, the consumer in this situation can adopt two types of strategies: can decide to buy the product, at no risk of losing if he does not buy at that point of time, or can wait till the end, when the winners of auction and the price is revealed i.e. much similar to an option. They studied the structural properties of the problem. The research has come up with an equilibrium strategy for both kinds of strategies adopted by the customer, and has shown that customers will join the auction only if matches his valuation. They have claimed that their equilibrium strategy yield better revenues and give optimum results.

From this point on the survey, focus is more on the overbooking research literature.

2.8 Overbooking

Overbooking is one of the most successful revenue management practices in financial terms. Without some kind of overbooking, 15% of the seats in airline industry will be unutilized; which is a major portion of the revenue for all the airlines (Smith et al,
This reveals the significance of overbooking concept in the revenue management of a reservation based system and throws light into the revenue generation potential of this concept.

Overbooking as a practice is mainly concerned with capacity utilization in a system where reservation is prevalent. This practice can be deployed in any situation where customers can cancel the order or the value of asset reduces significantly after a particular deadline. The main capacity control problems in a revenue management system are capacity allocation and capacity utilization. Of these two, capacity allocation is achieved by optimizing demand mix among different customer segments and capacity utilization is achieved by controlled overbooking. But the noted revenue gain from capacity allocation is 5% as compared to the 15% of the capacity utilization. Despite this apparent advantage, overbooking as a practice has received less attention in academic literature and research.

The economic advantage in overbooking comes with obvious challenges too. One of the key flip sides of overbooking is denial of service to a booked customer which may result in and regulatory issues. So the idea is to control overbooking in such a way that unused capacity is utilized to the maximum without excess overbooking.

2.8.1 Supply Chain Perspective

This research is mainly focused on warehousing area of the supply chain, trying to find out more innovative methods for revenue generation with the existing infrastructure. From this section onwards we will try to concentrate more specifically on warehousing and explore the potential of applying revenue management principles to this area
A typical supply chain consists of suppliers, manufacturers, distributors, retailers and end users where flow occurs in the form of materials, products, services and information; and in the end money is realized. The activities performed in this typical supply chain are design, manufacturing, procurement, planning, forecasting, order fulfillment and distribution. Revenue management from a supply chain operations perspective is pricing, resource allocation and production decisions to match the supply and demand profitably. The goal of revenue management in supply chain management is to “deliver the right product to the right place at the right time for the right price, while minimizing system-wide costs and satisfying service requirements”. (Lecture, Dr Pinar Keskinocak, 2005)

A global view of supply chain will reveal that traditionally there exists disconnect between the supply side and demand side of a supply chain. This necessarily means that the supply side activities such as manufacturing, transportation, warehousing, order management and network design is not in perfect congruence with the demand side activities such as pricing, promotions and sales. Given the importance of supply chain operations in any system, this disconnect is an opportunity to research for improvement of the whole system and as a result create more revenue creation opportunities.

The state of academic literature and research carried out in these areas is considerably less and even understandably so, as this is one of the emerging areas of application. In the section ahead we will conduct a literature review of the available research performed in revenue management in overbooking and on overbooking in supply chains. A general review of the overbooking research areas is conducted, as it can
give valuable insights into the principles which can be applied to supply chains and other manufacturing areas.

To review the literature pertinent to overbooking, a further classification of areas of overbooking research is made. Overbooking, initially an airline revenue management principle is now applied as a critical driver of innovative revenue generation technique in supply chains, air cargo, healthcare, hotel industry, internet service providers, telecommunications. A review of each section of the industry is as follows.

2.8.2 Overbooking in Airlines

Subramanian et al (1999) formulated a seat allocation problem for airlines, considering overbooking and cancellation. They formulated their model as a markov decision process for seat allocation on a single leg flight. For the system considered they assume that overbooking depends on state and time dependent booking limits, for each and every fare classes. They showed that with the possibility of cancellations, an optimal policy depends on the remaining capacity as well as total capacity. The important observation of the model is that considering the effect of overbooking helps to gain 9% revenue over the model which does not consider the impact of overbooking. Also they showed the computational feasibility of their model.

Couglan (1999) extended this model for overbooking problem with more than one class, i.e. bookings where airlines have more than class. The research used the demand data of every class to determine the booking levels for each of those classes. Through the use of multi level search routines, an optimization model is developed for each class. This control level model is tested using real time data. The model is currently is used by the airline ‘Aer Lingus’ of Germany and it achieves 2% increase of revenue by considering
overbooking over the current model. As the conclusion of the research, author has mentioned that nesting is not considered in the model and the model does not guarantee an optimal solution, which is mentioned as possible avenue of future research.

Gosavi et al (2005) proposed a simulation based optimization model to solve the seat allocation problem considering the impact of overbooking. The model proposed by them deals with both single leg and multi leg seat inventory control network problems. They claim that using their heuristic considering the overbooking impact has led to significant revenue improvements.

Milbrant (2006) developed a method to calculate the overbooking factor. The study developed an approach named as Experience Based Admission Control (EBAC). The overbooking factor calculated in this study, takes into account the average peak to mean ratio of all the admitted travel flow links. The study proposed a type specific EBAC which takes into account different types of traffic with similar mean to peak ratios, and provides a better overbooking factor. The study provided a proof of this and compared it with traditional methods. The study claim that the use of this strategy will lead to better resource utilization compared to the traditional booking patterns.

2.8.3 Overbooking in Air Cargo

Kasilingam (1996) conducted a study on the capacity utilization in air cargo, to reduce the spoilage or over sale of the available capacity. The study considers a situation where the capacity of cargo accommodated is known with certainty, but due to variety of reasons like payload and the weight of the boarding passengers makes the cargo capacity to be treated as a variable factor. The study derived the overbooking levels after considering the above factors, to improve the revenue over a traditional booking of the
Moussawi & Cakanyildirim (2005) studied a two dimensional cargo overbooking problem. They formulated the problem with a profit maximization objective. The aggregate formulation is solved under finite and infinite booking request and the overbooking limits are arrived with respect to the show up rates. They gave an upper bound for the problem and claim that this gives an optimal solution for more than 60% of the cases.

Popescu et al (2006) studied the show up rate problem in both passenger and air cargo business. They point out the significance of show up rates on the overbooking problem in air cargo business, as most of the airlines use this number as a key determinant to arrive at overbooking estimates. The current practice uses the same methodology for overbooking estimate of passenger and air cargo business. But the authors proposed a different methodology for overbooking estimate of air cargo. This model as they claim calculates the discrete estimate of show up as compared to normal estimate of show up rates, which leads to better utilization of the capacity. They show that improved estimate of show up rate leads to improved profits and customer service.

2.8.4 Overbooking in Hotel Industry and Telecommunications

Toh & Dekay (2002) conducted a research on the overbooking possibilities in hotel industry. The statistics noted in the research are, occupancy rate in hotel industry around 72%, with ample no shows rates and unexpected delays. These results reveal a possibility of overbooking in hotel industry. They point out that the hotels have started charging penalty for early departure, which creates capacity utilization problem. They derived a mathematical model for overbooking and have shown that overbooking of the
facility, results in better profits by increased capacity utilization.

Overbooking is used in telecommunications network to increase capacity utilization of the existing facility. Huang et al (2006) studied the network industry in detail and proposed that if overbooking factor is used, revenue gains can be achieved without incurring additional costs. They mention in the study that, most of the present calculations use a single factor for the overbooking requests. The research proposes a piece wise linear approach model for overbooking calculations. They claim that using this model for overbooking calculations will lead to better capacity utilizations and will decrease the loss rates. Also they claim that this method will increase the profits for network service providers.

Ball et al (2006) extended this research by finding out an optimal overbooking ratio considering a factor Quality of service (QoS). The research studies a potential problem of the service quality declining as more requests are accepted than the available bandwidth. So they proposed a model for controlled overbooking so that optimal profits can be attained without loss of service quality and good will. They claim that this model will yield optimal profits without loss of service quality.

2.8.5 Overbooking in Supply Chains

To our knowledge, Sirong (2005), the dissertation study conducted at University of Texas, is the first research literature to explore the application of revenue management in supply chain. The research studies the main cost drivers in supply chain, namely flexibility and revenue management. The first part of the research shows the importance of lead time flexibility, in terms of the revenue it can generate. The second part of the dissertation deals with overbooking in two dimensional cargo revenue management
problem and compares it with one dimensional problem. The study developed a region of acceptance of booking of cargo, in the two dimensions of weight and volume, and show that the booking is accepted if it falls within the specified range. The research shows that, flexibility increases the responsiveness of supply chain and hence reduces the operational risks, while revenue management increases the revenue and profit of the firms significantly.

This study is focused on warehousing operations of third party logistics firms and revenue generation potential of applying overbooking principles on its warehousing operations. From the literature reviewed, it is observed that there is no research conducted on the application of revenue management principles in warehousing. Kasilingam (1996) developed a newsvendor based model for air cargo overbooking. But the research did not considered service level for obtaining the value of overbooking level, and service level is one of a significant factor in third party logistics warehousing situations. Popescu et al (2006) have developed overbooking models with service level, but they have set upper bound and lower bound on authorized capacity, as the research was focused on impact of cargo show up rate on overbooking policy. The lower bound of capacity is to account for freight forwarders who bid for cargo space six to twelve months before the airplane leaves. Our model will extend the Kasilingam (1996) cost model, and we consider service level also for arriving at the overbooking limit. Also our research is different from Popescu et al (2006) as the third party logistics warehouse don’t operate under lower bounds and upper bounds of capacity, as in our model we don’t consider the people bidding for warehouse space and we don’t consider any upper limit on overbooking because any amount of backup can be arranged depending on the show up
CHAPTER 3

METHODOLOGY

3.1 Overview

The focus of this research is to study the potential benefits of applying overbooking concept in warehousing operation of third party logistics (3PL) firms, which provide warehousing and distribution services to multiple customers. Overbooking, as the term indicates is the practice of accepting more reservations than the available capacity. This is to account for all the customers not using the capacity up to their limits and also the cancellations which may occur on the capacity usage. This creates a revenue generation opportunity, which is proposed to be tapped by employing overbooking concept of revenue management.

A third-party logistics (3PL) provider is the provider of third party logistics or outsourced service provider of supply chain management function to companies. For instance, a manufacturer of goods wants to sell his merchandise to big retailers such as Wal-Mart or Macys, and if he does not have the supply chain function tied up to his firm, he will typically have to obtain the service of a third party logistics (3PL) firm. Third party logistics (3PL) environment is selected as the study is focused on outsourced suppliers of warehousing function. One of the various functions of these firms is integrated warehousing and transportation services. This research is focused on the warehousing section and the application of the overbooking concept in revenue management to increase revenue.
3.1.1 Justification for a Change in Current Warehousing Paradigm

To justify a change in the current warehousing paradigm, a review of the current set up is relevant. One of the key strengths of large retail chains is their superior supply chain operation. From the perspective of warehousing and distribution, they have efficient warehousing operations. This helps them to store products in an efficient way, which eventually reduces their transportation and other logistics cost compared to fragmented retailers. For example, a large retailer is importing goods from low cost locations like China and Far East; it can store these products according to the market demand and save money on transportation and other logistics costs involved.

To compete with such a model, the fragmented retailers need more efficient warehousing operations. This is one of the key areas, as this can reduce various logistics cost involved. This is an area where third party logistics (3PL) players can help these businesses. If the retailers can generate the demand and if these 3PL players can optimize their warehousing operation, it can act as a competitive business model.

3.1.2 Proposed Warehousing Paradigm

In this study a new warehouse paradigm is proposed, to support an alternate competent supply chain model. This is to compete against superior supply chain operations of the large retail chains.

Most of the large retail chain strength’s lies in the economy of scales and their superior operational efficiency. To compete against such a model, the fragmented retailers need group synergies in their operations. The proposed model consists of a network of fragmented retailers in a region served by a third party logistics (3PL)
operator. This implies that the 3PL operator will provide the warehousing operations to this network of fragmented retailers. This will create a synergy in operational efficiency of the supply chain network for these smaller players, which can help them compete in cost with the larger retailers.

To generate more operational efficiency, an alternate logistics network can be created by group synergy between various 3PL firms, so they can form an alternate superior supply chain network. This will reduce the operational cost and the logistics cost which can eventually help the second line players to fight in cost with the major players.

An evaluation of the contract terms for occupying the warehouse space by customers is important, in this scenario. The situation discussed above is dynamic and cancellations can occur more often in such an environment. So the long term contracts (yearly) for the warehousing operation, which is common, has to be replaced by short term contracts (monthly). Accepting short term contracts will help to make the cancellation terms easier as the warehouse space is precious, since is serving a larger network. This implies that there should be flexibility in warehousing contracts in terms of the length of the contract and cancellation terms.

This environment can create more demand for the warehouse space and as part of the larger goal to increase the operational efficiency to reduce cost, innovative warehousing techniques is studied in this research.

3.2 Problem Environment

A third party logistics (3PL) company is running a warehousing and distribution operation. The business model of such a firm operates in a way that, it sells its warehouse space to multiple manufacturers or sellers who want to use its space. The efficiency of
operation of the business depends on how efficiently it can manage its capacity. In purely system terms, it can be said that this is a capacity utilization problem.

In a revenue management perspective, there is a possibility of selling the capacity above the firm’s available capacity, i.e. there is a possibility of overbooking the capacity. This is because; some of the customers to whom the space is sold may not use the space up to their limits. Most of the warehouse business models are driven by the uncertainty tied up with manufacturing and general conditions. Some of them are seasonal peaks, planned inventory piling up for manufacturing shutdown, discount buying of large scale and rapid growth. This indicates that there are seasonal peaks and valleys in the occupancy rates.

Another problem which can occur in these business models is the cancellation of warehouse space bookings. Cancellation, in the competitive business environment is a phenomenon which is inevitable. So cancellation terms should be flexible, but at the same time the fact that the warehouse dealer may not be able to sell off the space, if the cancellation is made after a particular period, should be taken into consideration.

The research will attempt to solve the problem of better utilization of available capacity in the warehousing operation of a third party logistics firm (3PL), by applying the overbooking techniques in revenue management. The objective of the research is to discuss a limit by which the available capacity can be overbooked, such that we can maximize the revenue obtained using this strategy. In the section ahead, the proposed model is elaborated.
3.3 Methodology

As explained above, this is a capacity utilization problem. Two major factors contribute to the capacity under utilization: capacity opportunity and cancellations.

3.3.1 Capacity Opportunity

Some of the customers to whom the space is sold do not always use the space up to allotted capacity due to various uncertainties, as explained above. This implies that only a certain percentage of warehouse space will be occupied at a particular time (occupancy rate) and the rest will be empty. This occupancy rate at a particular period of time has to be quantified to obtain the measure of capacity utilization. The ratio of warehouse space occupied at a particular period of time to the total capacity is termed as ‘capacity show up rate’. This term will measure the capacity utilization at a particular time. It also defines the capacity opportunity, i.e. the capacity which is unoccupied when the warehouse space is sold out.

3.3.2 Cancellations

The cancellation of the capacity is another factor that contributes to the under utilization of the capacity. Cancellation in most of the business situations is a factor which is inevitable. A sound solution to solve the cancellation problem is to impose a penalty if the customer initiates the cancellation of the contract after a specific period. This is to share the risk of the space being unoccupied, if the logistics firm is not able to sell the space after a specific period. Also at the same time the firm can sell the space to other customers, which generates more revenue for the firm.
3.3.3 Overage Cost

While the proposed solution to explore the capacity opportunity problem is to overbook the capacity, a situation can occur where all the customers to whom the capacity is sold, use it at the same time. In this case, a clear back up capacity has to be arranged for the overbooked customers. This implies additional cost for the back up capacity. The additional cost involved can be termed as ‘overage cost’.

3.3.4 Unused Capacity Cost

A certain amount of space, as explained above is not used by the customer. This is viewed as an opportunity. The opportunity cost of the customer not using the space to their limits is called unused capacity cost, which implies that this is the revenue loss to the firm because of the capacity occupying the warehouse is less than what it can hold, which results in firm not able to fill the total capacity.

The proposed solution to the capacity opportunity problem is to overbook the available capacity. As stated in the objective, the next section of the study will focus on deriving a limit by which the available capacity can be overbooked. This will give an idea of how much above the nominal available capacity one can accept reservations, so that total cost is minimized.

3.4 Model Formulation

The following notations are defined.

\[ K = \text{Capacity of the warehouse} \]

\[ O = \text{Overage cost per unit of warehouse capacity incurred to the 3PL provider} \]

\[ U = \text{Unused capacity cost per unit of warehouse capacity incurred to the 3PL provider} \]

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\( K_o = \) Capacity overbooking level (decision variable)

\( r_c = \) Capacity show up rate (actual show (used) capacity, varies between 0 and 1)

that follows a uniform distribution between A and B

\( s = \) Admissible service level

The objective of the mathematical model is to minimize the expected total cost under a service level constraint. Expected total cost consists of two elements: expected cost of overage and expected cost of unused capacity as shown below.

\[
E(\text{TC}) = E(\text{CO}) + E(\text{CU})
\]

In the following sub-sections, different components of this model are defined.

### 3.4.1 Derivation of Expected Total Cost Function

In order to introduce the terms of expected cost of overage and expected cost of unused capacity, show up and desired show up for an ideal warehouse setting has to be introduced.

In defining the show up on a particular day, it is assumed that capacity is booked up to overbooking level (\( K_o \)). Therefore,

\[
\text{Show up on a particular day} = K_o \times r_c
\]

For an ideal warehouse setting, to completely occupy the warehouse the above value of show up is desired to be equal to warehouse capacity.

\[
\text{Capacity (K)} = K_o \times r_c
\]

These terms will be used in the following sections to derive the expected costs.

a. Expected Cost of Overage

Based on the above ideal warehouse setting, overage condition occurs when
\( r_c > \frac{K}{K_o} \). The amount of overage can then be calculated as:

\[
\text{Amount of overage} = (r_c * K_o) - K
\]

Consequently the cost of overage is:

\[
\text{Cost of overage} = O * [(r_c * K_o) - K]
\]

Assuming capacity follows a continuous probabilistic distribution, the expected number of overage, \( E(O) \), can be defined as follows:

\[
E(O) = \int_{K/K_o}^{1} [(r_c * K_o) - K] * f(r_c) \, dr_c
\]

Where \( f(r_c) \) is probability density function.

Consequently the expected cost of overage \( E(Co) \) can be represented as,

\[
E(Co) = O \int_{K/K_o}^{1} [(r_c * K_o) - K] * f(r_c) \, dr_c
\]

b. Expected Cost of Unused Capacity

Based on the above ideal warehouse setting, unused capacity condition occurs when \( r_c < \frac{K}{K_o} \). The amount of unused capacity can then be calculated as:

\[
\text{Amount of unused capacity} = K - (r_c * K_o)
\]

Consequently the cost of unused capacity is defined as:

\[
\text{Cost of unused capacity} = U * [K - (r_c * K_o)]
\]

Assuming that capacity follows a continuous probabilistic distribution, the expected unused capacity \( E(U) \) can be defined as follows

\[
E(U) = \int_{0}^{K/K_o} [K - (r_c * K_o)] * f(r_c) \, dr_c
\]

Where \( f(r_c) \) is probability density function. And the expected cost of unused capacity
E (C_U) can be represented as,

\[ E (C_U) = U \int_0^{K_{/K_0}} [K - (r_c * K_0)] f (r_c) d r_c \]

c. Expected Total Cost

The expected total cost as defined above is the sum of expected overage cost and unused capacity cost. In third party logistics warehouse overbooking, the backup capacity is an important factor in the decision of the amount one can overbook. Even though this is uncertain as it depends on other third party backup spaces, most businesses have an estimate of the range of capacity backup spaces available. To account for this it is assumed that total capacity of the warehouse K follows a distribution, with probability density function z(K), which is defined over the region [M1, M2]. So the expected total cost equation is defined as follows:

\[
E(TC) = \int_{M1}^{M2} \left[ O * \int_{K_{/K_0}}^1 [(r_c * K_0) - K] * f (r_c) dr_c + U * \int_0^{K_{/K_0}} [K - (r_c * K_0)] f (r_c) dr_c \right] Z(k) dK
\]

(3.1)

3.4.2 Service Level

Service level is significant as in third party logistics (3PL) situation business depends on certain major customers and the service level to these customers is a key measure. As defined by Talluri & vanRyzin (2004) “A natural measure of service level is the long run fraction of customers who are denied service, which we call Type 2 service level denoted by S_{2}(x)”. This measure is defined mathematically as:

\[
S_{2}(x) = \frac{E[(Z(x) - C)^+]}{E[Z(x)]} = \frac{\sum_{k=C+1}^{x} (k - C) P_x(k)}{x(1 - q)}
\]
Where $S_2(x)$ is the service level, $C$ denotes the physical capacity, $x$ denotes the overbooking limit, $q$ is the probability that a current reservation at hand shows up at the time of service, $Z(x)$ denotes the number of customers who show up provided that there are $x$ reservations at hand and $P_x(k)$ denotes the probability mass function.

In this research, we use the above concept of service level in overbooking environment, to arrive at our value of service level. Our value of service level is defined as:

$$1 - \frac{\int_{M_2}^{1} \int_{K/K_0}^{1} [(r_c*K_o) - K]* f(r_c) dr_c z(K) dK}{K_o * E(r_c)} \geq s$$ (3.2)

### 3.4.3 The Model

Based on the above derivations, the mathematical model to calculated allowable overbooking to minimize total cost subject to service level constraint is presented as follows.

$$\text{Min} \int_{M_1}^{M_2} \left[ O \int_{K/K_0}^{1} [(r_c*K_o) - K]* f(r_c) dr_c + U \int_{0}^{K/K_0} [K - (r_c*K_o)]* f(r_c) dr_c \right] Z(k) dK$$ (3.3)

Subject to,

$$1 - \frac{\int_{M_2}^{1} \int_{K/K_0}^{1} [(r_c*K_o) - K]* f(r_c) dr_c z(K) dK}{K_o * E(r_c)} \geq s$$

$K_o \geq 0$

Solving the above mathematical model will determine the value of overbooking limit ($K_o$) under an agreed specified service level condition. Analysis of the model is given in the next section.
CHAPTER 4

SOLUTION AND RESULTS

4.1 Solution Approach

The mathematical overbooking model discussed in the previous chapter is verified in this chapter. Consequently the model is validated in the next section with the help of case studies and the comparison of its results to the previous research. A sensitivity analysis of the model is performed to study how the variation of key parameters changes the output from the model.

Model (3.3) from previous chapter, is a nonlinear optimization problem. LINGO is used to solve the optimization problem. To prepare the model for LINGO certain transformation has been made which will be discussed with the case studies.

4.2 Case Study of the Model

Case1: The case of a warehouse is considered where capacity show up rate (\( r_c \)) of the warehouse is uniformly distributed between 80% and 100%, i.e. \([0.8, 1.0]\) and the probability density function value 5, i.e. \( f (r_c) = 5 \). The overage cost and unused capacity cost of overbooking are both taken as $10/unit of the warehouse capacity (i.e. the values of overage and unused capacity cost are assumed equal). It is also assumed that capacity follows a uniform probabilistic distribution over the range \([100,120]\) with probability density function of \( z (K) = 1/20 \). The expected value of show up \( E (r_c) \) is assumed to be 0.9 and the service level value (s) is assumed to be 87%.
To transform the formulation to a form suitable to LINGO, initially the derivative of equation (3.1) in the previous chapter is taken, with respective to $K_o$, and is set to zero as follows.

\[
U \cdot \int_{M_1}^{M_2} \int_{A}^{B} r\cdot f(r) \cdot dr \cdot z(K) \cdot d(K) - O \cdot \int_{M_1}^{M_2} \int_{A}^{B} r\cdot f(r) \cdot dr \cdot z(K) \cdot d(K) = 0 \quad (4.1)
\]

Where A and B are upper and lower bounds of show up rates of capacity. Now solving the integrals;

\[
U \cdot \int_{M_1}^{M_2} \frac{K}{2K_o^2} - \frac{A^2}{2} \cdot dK - O \cdot \int_{M_1}^{M_2} \frac{B^2}{2} - \frac{K}{2K_o^2} \cdot dK
\]

\[
U \cdot \left[ \frac{M_2^3}{6K_o^2} - \frac{(A^2/2 \cdot M_2)}{2} \right] - \left[ \frac{M_1^3}{6K_o^2} - \frac{(A^2/2 \cdot M_1)}{2} \right]
\]

\[
O \cdot \left[ \left( \frac{B}{2} \cdot M_2 \right) - \frac{M_2^3}{6K_o^2} \right] - \left[ \left( \frac{B}{2} \cdot M_2 \right) - \frac{M_1^3}{6K_o^2} \right]
\]

Now substituting the numerical values from case 1

\[
10 \cdot \left[ \frac{120^3}{6K_o^2} - \frac{(0.8^2 \cdot 120)}{2} \right] - \left[ \frac{100^3}{6K_o^2} - \frac{(0.8^2 \cdot 100)}{2} \right] = 10 \cdot \left[ \frac{120}{2} - \frac{120^3}{6K_o^2} \right] - \left[ \frac{120}{2} - \frac{120^3}{6K_o^2} \right]
\]

\[
\frac{288000}{K_o^2} - 38.4 - \frac{166666.67}{K_o^2} + 32 = 60 - \frac{288000}{K_o^2} - 50 + \frac{166666.67}{K_o^2}
\]

\[
\Rightarrow \frac{288000}{K_o^2} - \frac{166666.67}{K_o^2} - 8.2 = 0
\]

To convert the service level constraint to a suitable form for LINGO, the constraint equation (3.2) is taken and transformed as follows,

\[
1 - \frac{\int_{M_1}^{M_2} \int_{K/K_o}^{1} [(r\cdot K_o) - K] \cdot f(r) \cdot dr \cdot z(K) \cdot dK}{K_o \cdot E(r)} \geq s \quad (3.2)
\]
Substituting the numerical values from case study 1 in equation (3.2) results in:

\[
\begin{align*}
&\left[ 60k_o - 7200 + \frac{288000}{k_o} \right] - \left[ 50k_o - 5000 + \frac{166666.67}{k_o} \right] \leq (1-s) * k_o * 0.9 \\
&\left[ 10k_o - 2200 + \frac{121333.33}{k_o} \right] \leq (1-s) * k_o * 0.9
\end{align*}
\]

(4.2)

For a service level value of 87% equation 4.2 results in

\[
\begin{align*}
&\left[ 10k_o - (1-0.87)*k_o*0.9 - 2200 + \frac{121333.33}{k_o} \right] \leq 0 \\
&\left[ 9.88 * k_o - 2200 + \frac{121333.33}{k_o} \right] \leq 0
\end{align*}
\]

Note that the notation L represents the value of overbooking level (K_o).

The LINGO Model of the equation (4.1) and (4.2) is shown below. One more point to be noted at this instance in the model is a cost minimization. Since we differentiated equation (3.1) and set it to zero, to the get to equation (4.1), in the LINGO model we maximize the equation in effect to get the minimum value, i.e. In the function space if
one differentiates an equation and set that equation to zero, by calculating the maximum value, actually we are calculating the maximum of all the minimum’s to get the best minimum value.

MODEL:
MAX = 288000/L*L - 166666.67/L*L - 8.2;
9.88*L + 121333.33/L - 2200 <= 0;
L >= 0;
END

Solving the above LINGO model results in the overbooking limit of 122.06. This means that in the above case the model allows an overbooking of 22.06% above the normal warehouse capacity, for an agreed service level of 87%, which is 22% cost savings than not practicing overbooking. This implies that if a warehouse space of 100,000 square feet is considered and unit cost of warehouse space is $5, then 22060.3 (0.220603 * 100000) square unit of space can be overbooked resulting in $110,301.5 (22060.3 * 5) of cost savings.

4.3 Model Validation

To validate the model, cost parameters, overage and unused capacity costs, are changed and their effects are studied. This is performed with the objective of finding out whether the model is relevant to the calculation of overbooking limit. Intuitively, for a higher value of overage and a lower value of unused capacity cost, overbooking should be less and for a higher value of unused capacity cost and a lower value of overage cost,
the value of overbooking should be high. The model is subjected to the above mentioned conditions and the results are used to validate the model.

**Case 2a:** The previous case study is considered and the cost of unused capacity is reduced to $8/unit without changing other parameters of the model. The LINGO model is generated as follows and solved.

```
MODEL:
MAX = 288000/L*L - 166666.67/L*L - 8.4;
9.88*L + 121333.33/L - 2200 <= 0;
L >= 0;
END
```

The value of overbooking limit obtained is 121.2480. Comparing this value with the result from the previous case indicates that as unused capacity cost is reduced, the value of overbooking is reduced from $122 to $121.

**Case 2.b:** For this case study the cost of unused capacity is further reduced to $0 without changing other parameters of the system. The solution to this model indicates an overbooking value of 101.1055 (~101) which is much lower that the original value of 122. The overbooking value in this case is negligible as the cost of overage is relatively high as compared to the unused capacity cost. The results of these cases studies are summarized in Table 4.1.
TABLE 4.1
COMPARATIVE ANALYSIS OF UNUSED CAPACITY COST AND VALUE OF OVERBOOKING

<table>
<thead>
<tr>
<th>(Overage cost, unused capacity cost)</th>
<th>Value of Overbooking</th>
</tr>
</thead>
<tbody>
<tr>
<td>(10,10)</td>
<td>122</td>
</tr>
<tr>
<td>(10,8)</td>
<td>121</td>
</tr>
<tr>
<td>(10,0)</td>
<td>101</td>
</tr>
</tbody>
</table>

Case 3.a: Two other tests were carried out in which the original problem data is used but the overage cost was changed from $10/unit to $8/unit and $0/unit. The results are summarized in Table 4.2. As may be noticed from the results, as the overage cost is reduced without changing of cost parameters, the overbooking value has increased.

TABLE 4.2
COMPARATIVE ANALYSIS OF OVERAGE COST AND VALUE OF OVERBOOKING

<table>
<thead>
<tr>
<th>(Overage cost, Unused capacity cost)</th>
<th>Value of Overbooking</th>
</tr>
</thead>
<tbody>
<tr>
<td>(10,10)</td>
<td>122</td>
</tr>
<tr>
<td>(8,10)</td>
<td>125</td>
</tr>
<tr>
<td>(0,10)</td>
<td>136</td>
</tr>
</tbody>
</table>

From the results of cases 2.a and 2.b one can observe that as the overage cost is high and unused capacity cost is low, overbooking value reduces than the case 1 where both overage and unused capacity cost is the same. On the other hand from case 3.a and case 3.b, as the value of overage cost is low and unused capacity cost is relatively high,
overbooking value increases. So the conclusion is that, the model is relevant to the situation.

### 4.3.1 Service Level

Service level is defined in the previous chapter of the study as, “A natural measure of service level is the long run fraction of customers who are denied service, which we call Type 2 service level denoted by $S_2(x)$”. The model is compared for different values of service level. The original problem data values are used, and the value of service level is varied. For service level values of 90%, 75% and 50%, the overbooking values are recorded in the Table 4.3

<table>
<thead>
<tr>
<th>Service level</th>
<th>Value of Overbooking</th>
</tr>
</thead>
<tbody>
<tr>
<td>90%</td>
<td>120.5867</td>
</tr>
<tr>
<td>75%</td>
<td>128.3695</td>
</tr>
<tr>
<td>50%</td>
<td>138.8923</td>
</tr>
</tbody>
</table>

It can be noted from the table that, as the value of service level decreases the overbooking value increases. This infers that for lower value of service levels one can afford to book more customers. Some customers can be denied space at these lower values of service level agreements.

### 4.3.2 Comparison of Results and Validation

The results of model are compared with those given by Kasilingam (1997). Kasilingam (1997) derived a model for air cargo overbooking problem. In that research
the author did not consider service level as a constraint. Therefore, the results of the proposed modeled at 90% assumed service level are compared with the published results. Specific information on the problem that was solved is given as follows.

**Case 4:** The case of the warehouse is considered when capacity show up rate i.e. $r_c$ of the warehouse is distributed over 80 to 100%, i.e. $[0.8, 1.0]$. The overage cost and unused capacity cost of overbooking is taken as $\$ 10/unit of the warehouse capacity i.e. the values of overage and unused capacity cost is taken as equal. Value of service level is taken as 90%. These values are used as input parameters for the model. LINGO model of the above case is shown below:

```
MODEL:
MAX = 288000/L*L - 166666.67/L*L - 8.2;
9.91*L + 121333.33/L - 2200 <= 0;
L >= 0;
END
```

The value of overbooking limit obtained is 120.5867 (~120), i.e. in the above case the model allows an overbooking of 20% above the normal warehouse capacity for an agreed service level of 90%.

In Kasilingam (1997) model for air cargo overbooking, the result recorded is 121.2 i.e. 21% of overbooking. So the results are comparable. In fact, this research introduced an additional constraint on service levels, as this is important to warehouse situation. A sensitivity analysis of the model is conducted in the Section 4.5.
4.4 Verification of the Model

For verifying the model, the calculations of the model with the parameters and the values of integration, are checked several times for consistency of results. The model is systematically explored for different set of values and seems to be consistent.

4.5 Sensitivity Analysis

Sensitivity analysis studies how the output of a model varies with the corresponding change in the input parameters. A model is considered sensitive if a change in the input parameter changes the value of model output.

Sensitivity analysis is significant as inputs of any model is subject to various uncertainties including errors in measurement of values, absence of relevant information, partial understanding of driving mechanisms. Also models have to adjust themselves to any natural variability occurring in a system. These factors restrict the confidence in the response or output given by any model. Good modeling practices require evaluation of the confidence in the modeling practices, and its outcomes. Sensitivity analysis is a good tool to evaluate the confidence in the model.

In this section robustness of the model is assessed by varying the values of (i) service level and (ii) mean value of show up. The above factors are chosen since they are significant values in the modeling environment.

4.5.1 Effect of Service Level on Overbooking Limit

Service level is a key input parameter in a warehousing situation. For this analysis, the service level value is varied from 90 to 98 % at intervals of 2%, and the
value of overbooking is observed. The results are given in the Table 4.4 and variation is shown in Figure 4.1

TABLE 4.4

EFFECT OF VARIATIONS IN SERVICE LEVEL ON OVERBOOKING VALUE

<table>
<thead>
<tr>
<th>Service level (s)</th>
<th>Overbooking limit (K_L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>98%</td>
<td>110.2507</td>
</tr>
<tr>
<td>96%</td>
<td>113.6258</td>
</tr>
<tr>
<td>94%</td>
<td>116.3014</td>
</tr>
<tr>
<td>92%</td>
<td>118.2014</td>
</tr>
<tr>
<td>90%</td>
<td>120.5867</td>
</tr>
</tbody>
</table>

Figure 4.1: Service level vs. Overbooking Limit

From the results it can be observed that, as the value of service level decreases the value of overbooking increases. This is intuitively correct as the promised service level to the customer is less, one can afford more overbooking, which means some customers with lower service levels cannot be guaranteed space all the times.
4.5.2 Effect of Mean Show up on Overbooking Limit

Show up (used capacity) is an equally important parameter as this value determines how much overbooking one can afford. Mean show up is chosen because it has a distribution, as different customers of the warehouse occupy the warehouse space at different rates. For this analysis, in case study 4, mean show up is varied from 0.9 to 0.2 at intervals of 0.2 and the value of overbooking is observed. The results are given in Table 4.5 and variation is shown in Figure 4.2.

TABLE 4.5
EFFECT OF MEAN SHOW UP ON OVERBOOKING

<table>
<thead>
<tr>
<th>Mean show up (E(r))</th>
<th>Overbooking limit (Ko)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>120.58</td>
</tr>
<tr>
<td>0.7</td>
<td>126.44</td>
</tr>
<tr>
<td>0.5</td>
<td>140.99</td>
</tr>
<tr>
<td>0.4</td>
<td>152.07</td>
</tr>
<tr>
<td>0.2</td>
<td>171.60</td>
</tr>
</tbody>
</table>

Figure 4.2: Mean show up vs. Overbooking limit
From the results it can be observed that, as the value of show up decreases the value of overbooking increases. This is intuitively correct as the show up decreases one can overbook more so that capacity can be utilized better. When show up drops significantly the value of overbooking goes up high.

4.6 Conclusion

The model proposed gives a value of overbooking for a warehouse of a 3PL firm taking into account the show up of customers and the agreed service level to the customers. This is advantageous for the business because if the booked customers fail to use the space already sold, the warehouse can obtain additional revenue on already sold space by overbooking after taking into account the overage cost which may incur, if all the booked and the overbooked customers show up together. In this process model helps the business to keep an eye on the service level too, as too much overbooking and bumping of customers may bring down the reputation of the business.

4.7 Competition

From a Fundamental Principle of Microeconomics perspective, for a perfect competitive structure to be present it must have four characteristics:

1) Numerous buyers and Sellers
2) Homogenous product
3) Knowledge or sufficient information
4) Free entry

Such a competitive structure encourages a strong sense of price competition, which in turn will lead to output and price at the demand and supply equilibrium levels.
In the case of monopolies the perfect competition theories cannot be applied. This leads to the classification of industries and markets into:

1) Perfect competition
2) Oligopoly
3) Monopolistic situation
4) Monopolistic competition

Of these the Oligopoly and Monopolistic competition can be grouped together.

Any business which satisfies the first four rules will be having a perfect competition and those others will be facing an imperfect one. From here onwards the study will focus on problems more specific to the situation.

In the proposed scenario of synergy among various 3PL players in the warehouse problem, there can be situations where some of the players disagree to cooperate. This may be with the intention of stopping one player from gaining unfair advantage due to overbooking the facility and accumulating more profits. This surfaces up a problem of the initial player not able to overbook, as the raising of prices for the back up capacity or other competitive measures carried out by the competition will erode the benefits obtained by the overbooking.

In such a situation, if a warehouse W1 overbooks and faces a situation where all the customers show up, then it has to arrange for a back up. To tackle this situation under usual circumstances, it has to approach another warehouse W2 which is the closest to it in terms of distance, as the goal is to reduce the logistics cost.

In a competitive game, if warehouse W1 approaches warehouse W2 for space to back up the overbooked volume, then warehouse W2 will raise the unit price for the
space. The consequence is that it erodes the benefits obtained of warehouse W1 due to overbooking. The same response will occur to warehouse W2, if it tries to overbook and approach warehouse W1 for overbooked space. Due to these mutual reactions, both of the parties cannot overbook when there is a definite potential to make profits due to overbooking.

The above problem is similar to a competition problem in game theory. The problem situation is similar to that of a non cooperative one, as both the parties do not cooperate, but any agreement of cooperation is a self enforcing one, as both parties are assumed to act independently and for their own benefit. To recommend an effective strategy for both of the players to make profits in a hostile situation, in this research we study Nash Equilibrium theory in Non Cooperative games, a groundbreaking research in theory of games. The problem situation is analyzed in context of Nash Equilibrium to make appropriate recommendations.

Nash Equilibrium develops a mathematical framework for analyzing non cooperative type of games. The games considered in this framework are n person games where each player has a pure strategy and there are payoffs for combination of each of these strategies. One major distinction between non cooperative and cooperative games is presence or absence of coalition and communication. The key contribution of Nash framework is the proof of existence of at least one equilibrium point in any finite game, which is really significant for this study.

The general theory of games is built on the assumption that various relationships and coalitions can be formed among different players in a game for their mutual benefit.
But the Nash framework assumes that each player in the game acts independently and coalitions or communication between players are absent.

Some of the terminology and concepts involved in Nash Equilibrium [76] are:

### 4.7.1 Finite Game

An n person game with n players, where each player (i) have its own finite set of pure strategies and a payoff (Pi), where Pi maps all the n-tuple of pure strategy into real numbers. An n-tuple is a set of n items, where each item is associated with a different player.

### 4.7.2 Mixed Strategy

A mixed strategy of each player i, is a collection of non negative numbers having unit sum and in one to one correspondence to its pure strategies i.e. $S_i = \sum C_{i\alpha} \Pi_{i\alpha}$, where $\sum_{\alpha} C_{i\alpha} = 1$ and all $C_{i\alpha} \geq 0$, so that it represents a mixed strategy. The pure strategies of each player i, is $\Pi_{i\alpha}$. Points $S_i$ are those in the simplex, whose vertices are $\Pi_{i\alpha}$. Also the simplex is considered as a convex subset of real vector space, which gives a process for linear combination of mixed strategies. Notations i, j, k is used as suffixes for players $\alpha, \beta, \gamma$, to indicate different pure strategies and $S_i, t, \mu$ used to indicate mixed strategies $\Pi_{i\alpha}$ indicate $i$ th players $\alpha$ th pure strategy.

### 4.7.3 Payoff Function

The payoff obtained for a player, by adopting a strategy. $S$ or $T$ denotes n tuple of mixed strategies, then, $S = (S1, S2, S3, \ldots \ldots \ldots Sn)$ the $\Pi(S)$ means $P (S1, S2, S3,$
Also n-tuple S can be regarded as a point in vector space, which is obtained by multiplying vector spaces of all mixed strategies. A convex polytope is formed by set of all such n tuples. It is obtained by the product of the simplices of the mixed strategies.

4.8 Concept of Equilibrium Point

In this section, we will discuss the Nash Postulates on the basis of which Nash concludes the existence of an equilibrium point in a finite game.

1. Nash’s First Postulate

\[ P_i(s) = \max all \gamma \in \gamma \left[ P_i(s; \gamma) \right] \]

“Equilibrium point is \( s \), such that each players mixed strategy maximizes his payoff, if the strategies of the others are held fixed”. Which implies that each players strategy is optimal with respect to that of others.

2. Nash’s Second Postulate

\[ \max all \gamma \in \gamma \left[ P_i(s; \gamma) \right] = \max \alpha [P_i(s; \Pi \alpha)] \]

3. Nash’s Third Postulate

Nash defines; \( P_i(s) = \max \alpha [P_i(s)] \), which yields a trivial necessary and sufficient condition for equilibrium below:

\[ P_i(s) = \max \alpha [P_i \alpha (s)] \]

4. Nash’s Fourth Postulate

If \( \Pi i \alpha \) is used in \( s \), then \( P_i \alpha (s) = \max \beta [P_i \beta (s)] \)
The above condition is another necessary and sufficient condition for equilibrium.

On the basis of above postulates, the existence of equilibrium points is established. The theorem proved on the basis of above postulates is “Every finite game has an equilibrium point”. On the above set of points of mixed strategies (S1, S2, S3, ……Sn) the point, S* is the point of equilibrium which yields an optimum strategy for a player, based on the optimal strategy of the rest if the players. Adopting this strategy according to Nash Equilibrium, each player maximizes his payoff from the game as a self enforced equilibrium exists among the players in any finite game.

4.8.1 Interpretation

In a third party logistics scenario where multiple warehouses try to overbook their facility to optimize the profits, competition game may occur where each player trying to stop the other player from overbooking by raising the back up capacity cost or other competitive strategies. In such a situation both players lose the competitive advantage by adopting this strategy. In these games the players involved don’t have complete information what strategy the competitor is going to adopt, i.e. the game is one of imperfect information. But the participants should have knowledge of relative advantages which can be obtained by adopting each and every pure strategy at their disposal.

Under these circumstances, Nash Equilibrium gives a clear direction for adopting a strategy mathematically. It establishes the fact that an equilibrium point in these non cooperative, finite and imperfect information games. So each player has to adopt an equilibrium point strategy which maximizes his payoff against the competitor’s maximum payoff. Adopting this strategy will help everyone to maximize his payoff and profits
CHAPTER V
CONCLUSIONS AND FUTURE WORK

Profits being the bottom line of every business, margins are shrinking in the face of extreme competition. In these scenario new and innovative methods of doing business is the main solution for businesses to stay competitive. The situation for supply chain operations is no different. The study focuses on new innovative techniques to increase the operating revenues of warehousing operation of third party logistics businesses. The contributions of the study in this area are discussed in the section ahead.

5.1 Contributions

• One of the most comprehensive academic surveys of the revenue management literature in operations area (manufacturing and supply chains) is performed in this study. This is performed with the focus of revealing the current state of literature, and also the future research directions in this emerging area in operations management literature.

• The study throws light into the possibility of using overbooking principles used in airline operations literature to third party logistics business. This is one of the key contributions of this research, as this can open up a new direction for future research towards this relatively new operations research literature.

• The study discusses an appropriate mathematical model to identify the overbooking limit to maximize profit in warehousing operations of third party logistics business.

• The research reveals the additional revenue generation potential of overbooking concept, in the warehousing operation of a third party logistics business.
• The research discusses the possibility of competition in situation where warehouses try to overbook their facility. In these non cooperative competitive game circumstances, the research studies a mathematical model which is suitable to this circumstance, the Nash Equilibrium. On the basis of this study, this research recommends an equilibrium point strategy to maximize the profits.

• One of the extensions possible is considering one of the customers as a major one, and a part of capacity is saved for that customer (say 40%) and the rest is sold in open market, which is spot market and only this part is overbooked(that means only 60% is overbooked)

This research opens up a new avenue for future research in operations area of revenue management literature. Significant directions for future research can result from this research. Some of the suggestions for future research are mentioned in the next section.

5.2 Future Research

• In this research, a single value of service level is offered to all the customers of the warehouse. One of the main extensions of this work can be, different customers types are offered different service levels according to their importance.

• The distance of the backup warehouse from the central warehouse where overbooking techniques are applied, can have a significant impact on the profits because of the logistics cost involved in back up. A model can be developed which gives the optimum distance of the back up warehouse from the central warehouse, so that overbooking profits can be maximized.
The use of genetic algorithms is proposed to obtain more close to optimal overbooking values for the mathematical model proposed. The current solution technique gives the local optimum solution i.e. close to optimal solutions values can be obtained by using genetic algorithm solution technique.

This research reveals the possibility of competition in warehouses. More detailed research is proposed to reveal possible new directions of research in conjunction with game theory.
LIST OF REFERENCES


