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FLEXIBLE PRICING POLICIES: INTRODUCTION AND A SURVEY OF IMPLEMENTATION IN VARIOUS INDUSTRIES

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CONTRACT REPORT

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Flexible Pricing Policies: Introduction and a Survey of Implementation in Various Industries

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ABSTRACT

Recent years have seen an increased interest in using yield management techniques to maximize profitability in capacity constrained situations. The general principles and history of yield management are reviewed. General implementation issues and techniques are discussed, and various industries are considered for impact and specific implementation issues. Service and manufacturing industries are compared for applicability and implementation differences.

PURPOSE OF RESEARCH

To review flexible pricing policies and their implementations in various industries in order to develop insights for applying the techniques to a manufacturing environment.

MAJOR RESULTS AND CONCLUSIONS

1) A review of flexible pricing policies in a variety of industries led to insights for the manufacturing industry. It is recommended that the following ideas have applicability to manufacturing and should be considered when determining flexible pricing policies:
   a) *Use rate classes:* Rate classes (or fare classes in the airlines) are used to group products or services. Segmentations such as service level (e.g., Business class or Coach class in the airlines) or time of purchase may be used. Many industries begin with two rate classes when implementing flexible pricing policies.
   b) *Segment the market:* Use product characteristics to segment the market. Suggestions are to use time (time of purchase or time of delivery), service level, or a combination of time and service to distinguish products.
   c) *Determine pricing and ordering policies:* Policies that need to be considered include refund policies (Will consumers be given a refund if prices drop? Under what conditions?) as well as overbooking policies (Will overbooking of orders be allowed? If so, what compensation will consumers receive if products are not available?) Policies of this type have been developed in the airline and rental car industries.
   d) *Develop performance measures:* Performance measures for flexible pricing policies should be developed; see Smith, et al (1992) for examples of these measures in the airlines.
   e) *Consider capacity as perishable:* Flexible pricing literature suggests that inventory should be perishable for models to be applicable. Although manufacturing products are not perishable, capacity can be thought of as perishable and the decision becomes partly a build/no build decision.
2) Among industries that use flexible pricing policies, the most useful industry to consider is the retail industry since inventory may be carried over time. Most applications thus far have been in retailing of fashion clothing. Specific characteristics of current flexible pricing models limit their applicability to the more general manufacturing environment. Examples of such characteristics include a lack of capacity limitations and demand which is non-increasing over time. Specific models relax some of these characteristics (see Federgruen and Heching (1999) for example).

3) No existing model captures all of the necessary components for implementing flexible pricing policies in a manufacturing environment. It was discovered that flexible pricing in this environment has a number of characteristics that make it a difficult problem to represent and solve. These will need to be addressed in a system that will determine flexible pricing policies in a manufacturing environment.
   a) Prices need to be determined for multiple classes of goods (for a single product). For example, a product may have both immediate delivery and delayed delivery, and prices would need to be determined for both classes.
   b) For product with a delayed delivery, the lead-time or delivery window needs to be determined.
   c) Inventory is non-perishable and may be carried over time.
   d) Demand over time may be non-increasing (thus, prices will not necessarily decrease over time).
   e) Decisions on when to produce need to be made, balancing inventory holding costs with production schedules.
   f) Capacity limitations should be taken into consideration.

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1 INRODUCTION

An increasingly competitive market requires companies to develop more sophisticated business strategies to remain successful. In a manufacturing world, these strategies might target production costs or distribution costs as potential areas for improvement. In addition, developing the right mix of products to offer customers provides another advantage to a market driven company. However, the truly successful company will determine business practices that integrate pricing decisions, inventory control strategies, and market demand. The sooner a company begins this integration, the more likely the company will leap ahead of its competition.

A number of industries have turned towards methods called yield management or revenue management[1] for insight in integrating pricing and inventory control. These methods use systems of flexible pricing based on product or service differentiations such as time of purchase or service level to match supply and demand more effectively. The techniques try to maximize a performance measure such as profit while remaining within the capacity limitations of the company. The impact of implementing flexible pricing policies can be significant—in the airline industry, it is estimated that yield management has increased revenues by 5 percent.[2]

Historically, service industries such as airlines, hotels, rental car agencies, etc. have provided the foundation for the implementation of revenue management techniques. Recent years have also seen applications of flexible pricing to product oriented environments like the retail fashion industry, where inventory is generally considered to be perishable. However, yield management techniques have not been sufficiently extended to apply to a general manufacturing environment. Although traditional pricing and inventory techniques are useful in a manufacturing environment, they are not sufficient to deal with complex situations that may include product differentiation by time of purchase or delivery date. A product and service oriented company who wishes to remain at the forefront of business practices will need to consider methods such as revenue management for integrating pricing and inventory control.

This report purports to examine the implementation of yield management in various industries and explore insights to applying the techniques to a manufacturing environment. First, some of the important yield management literature is reviewed, both generally and for specific industries. The basics of revenue management are outlined, and general implementation techniques are discussed. Case studies of implementation in airline and rental car industries are examined more closely, and some specific issues of implementation in those industries are explored. Examinations of currently implemented yield management methods are used to derive insights for applying the methods to a

[1] In the airline industry, "yield" has a very specific definition, and revenue management may more often be used to describe flexible pricing policies. However, the term yield management has evolved across many industries to generally apply to flexible pricing techniques and is perhaps the most common term used. In this paper, terms such as yield management, revenue management, and flexible pricing are generally used interchangeably.

[2] Belobaba (1987)

manufacturing environment. Flexible pricing policies are an important tool to launch a company into a new paradigm of strategic business planning.

2 LITERATURE REVIEW

The last ten years have seen a proliferation in writings on yield management and revenue management. As businesses have sought out yield management techniques to squeeze profits from ever more efficient business processes, researchers have responded to the needs.

2.1 Airline Industry

The development of yield management techniques began in the airlines in the 1960s, with published work by Littlewood (1972) on a two-fare single-leg problem and Rothstein (1971) on overbooking policies. Since then, many researchers have extended yield management techniques and the types of problems considered in the airlines.[3] For example, the decision rules developed by Belobaba for the two-fare problem were extended by Belobaba (1989) to apply to a multiple fare problem. Curry (1990) considers allocation of seats and fares with fare classes nested (grouped) by origin and destination. Belobaba (1987) also provides an overview of the status of inventory control within the airlines using a survey of current practices within the airlines.

Initially, revenue management techniques assumed that passengers chose from one particular fare class (without movement of passengers to a lower fare if it became available). Later, researchers were able to extend the techniques to allow for passenger diversions among fare classes. For example, Bodily and Weatherford (1995) simultaneously considered overbooking and allowed for passenger diversions. A comparison of various decision rules incorporating passenger diversions was performed by Belobaba and Weatherford (1996).

Kasilingam (1996) examined the differences between passenger yield management (PYM) and air cargo revenue management (CRM) and developed a model to use in CRM situations. Traditionally in the airlines, prices are assumed to be fixed input to a model; Weatherford (1997) included prices as decision variables and tested improvements under the more complex model. A rare discussion of actual implementation within an airline is provided by Smith, Leimkuhler, and Darrow (1992), each from American Airlines Decision Technologies. Three specific sub-problems are outlined and the evolution of yield management within American Airlines is explained.

2.2 Service Industries

[3] A sampling of the references are provided. For additional references, see Gallego and van Ryzin (1997) or Belobaba (1987) among others.

Yield management techniques have also been applied to other service industries such as hotels, cruise lines and rental car agencies. The basics of yield management, particularly in the lodging industry, are provided by Kimes (1989a). Orkin (1988) outlines some of the ideas behind yield management for hotels and provides examples of the types of calculations. Early work on overbooking of hotel reservations was performed by Rothstein (1974), and stochastic cancellations of customers in a single day period was considered by Liberman and Yechiali (1978). Bitran and Gilbert (1992) modeled hotel reservations incorporating uncertain arrivals, and Bitran and Mondschein (1995) extended previous models to include multiple day stays.

Pricing in the cruise industry is considered by Ladany and Arbel (1991); in particular they suggest ways of calculating the optimal number of price class segments and optimal prices assuming linear demand. Geraghty and Johnson (1997) provide a recent case study of yield management in the rental car industry and the impact of yield management on National Car Rental.

2.3 Retail Industry

The retail industry, particularly fashion items with seasonality, has also seen application of price differentiation policies. Although in this industry physical products are the focus rather than a service, the inventory is perishable so many of the same pricing techniques apply. However, pricing in this industry is generally not as flexible as in other industries previously considered for yield management applications. Since demand tends to decrease over a season, prices usually only decrease over that period of time (e.g., discounts, or markdowns). However, the basic concept remains the same--differentiate a product by some aspect (time in this case), and sell the same product at different prices to different customers.

Researchers have considered a variety of situations such as planned and unplanned markdowns, end of season clearance sales, and pricing with inventory replenishment. For example, Chakravarty and Martin (1989) modeled discounts and restock frequency of inventory with declining deterministic demand for single and multiple buyers. Subrahmanyan and Shoemaker (1996) considered a threefold problem: updating demand information and determining optimal pricing and optimal inventory level in a short selling season (such as the fashion industry). Determining prices (permanent markdowns) with continuous as well as a more realistic periodic review policy is studied by Bitran and Mondschein (1997). A similar problem is considered by Smith, et al (1998) with the addition of promotions of sales; they also compare results to alternate plans implemented by a retail store.

Clearance markdown policies are examined by Smith and Achabal (1998), and they compare results of the implemented policies at three retail chains. Gallego et al. (1997) perform an empirical analysis of pricing policies at an apparel retailer using the pricing model developed by Gallego and van Ryzin (1994) and suggest policies to improve revenues at the retailer.

2.4 Other Areas

A number of other industries, some less traditionally thought of as application areas for flexible pricing policies, have been receiving attention lately. In the railroad industry, Strasser (1996) suggests that yield management can smooth demand, thus reducing costs, while increasing service performance. Campbell and Morlok (1994) outline some of the differences between airlines and railroads and target intermodel transportation as a potential first application of revenue management. Electric power service is another possible application area, and Smith (1993) outlines a model for a real-time model with price changes based on supply and demand. Even the internet is a possible source of yield management applications--Paschalidis and Tsitsiklis (1998) analyze congestion-dependent pricing of internet service providers.

2.5 General Applications

In addition to the researchers who have examined revenue management in the context of specific industries, some have provided overviews or general models. Selected pertinent general references are presented below.

Weatherford and Bodily (1992) give an overview of the types of problems addressed and some of the models applied, as well as create a taxonomy to categorize revenue management problems. Their comprehensive taxonomy includes fourteen distinguishing elements such as the following: type of resource (discrete or continuous), prices (predetermined, set optimally, set jointly with inventory decisions), number of discount classes, diversions (yes or no), decision rule type, etc. They examine some of the currently solved problems, and they suggest that there is a large gap between the problems that have been considered already and more realistic problems that have not been considered yet.

Kimes (1989b) summarizes concepts behind yield management, components of the problem, and solution techniques used. Gallego and van Ryzin (1994) use intensity control theory to determine price as dependent on the inventory level and time in the horizon. They formulate the problem using stochastic demand, but they use deterministic demand to find a bound on the expected revenue for general demand distributions. In later work, Gallego and Van Ryzin (1997) develop a general dynamic, stochastic model to address pricing and inventory decisions simultaneously, and they apply the model to several network yield management problems (particularly in the airlines).

2.6 Application to Manufacturing

Although research does not indicate that yield management is being performed yet in a manufacturing environment, researchers have begun to address topics pertinent to implementing yield management in manufacturing.[4]

[4] Some of the papers presented below may also have applications in other areas (particularly the retail industry). However, they are presented here as among the ones most important to considerations of yield management in manufacturing.

Several researchers have been exploring offering a discount based on time or accepting order for future production. Moinzadeh and Ingene (1993) consider an inventory and pricing model with two goods—one good is available for immediate delivery and the second (substitutable) good is held for delayed delivery. The researchers indicate that setting prices to encourage consumers to switch to the delayed good may reduce inventory holding cost for the distributor. Weatherford and Pfeifer (1994) study the economic value to a manufacturer of accepting orders for future delivery using a single period newsboy model. A continuous review inventory model is explored by Cheung (1998), where a delayed delivery discount is offered when the distributor expects a stockout of a product. In a recent paper, Federgruen and Heching (1999) analyze a single item periodic review inventory model. Optimal pricing and inventory is determined, with inventory replenishment allowed at the beginning of each period.

Although some of the papers presented thus far (including those in the retail industry section) may seem to generate insights for manufacturing, none yet have considered capacity constraints or allowed for production after the start of the horizon. Balakrishnan, et al. (1996) consider the allocation of limited capacity between two product classes, although they do not examine optimal pricing of the products. Ishii and Nose (1996) analyze a perishable inventory situation that includes a capacity constraint and two types of customers (one who always buys the newest product) to determine the optimal ordering policy.

3 REFERENCE SUMMARY

References discussed in the literature review section above are presented in the following section, grouped by application area. Some model specifics are given for papers that include models, particularly whether the demand was assumed to be deterministic or stochastic.[5]

[5] Within those models that assumed stochastic demand, there was much variation. In many cases a specific distribution such as normal or exponential were assumed, or demand was allowed to depend only on price (and a random term). In some cases, linear demand models were assumed.

Table 1: Summary of Literature Review References

Reference	Industry	Specific Area	Model Specifics
Gallego & Van Ryzin (1994)	General	General Model	Stochastic, Deterministic Bound
Gallego & Van Ryzin (1997)	General	General Network Model	Stochastic
Weatherford & Bodily (1992)	General	Overview & Taxonomy of research	
Kimes (1989b)	General	Overview	
American Airlines	Airlines	General	
Belobaba (1987)	Airlines	Seat Inventory Overview; Survey of Practices	
Belobaba (1989)	Airlines	Multiple Fares (created EMSR)	Stochastic
Belobaba & Weatherford (1996)	Airlines	Comparison of Decision Rules	Stochastic
Bodily & Weatherford (1995)	Airlines/General	Passenger Diversions	Stochastic
Curry (1990)	Airlines	Nested Fare Classes	Stochastic
Kasilingam (1996)	Airlines	Comparison of Air Cargo and Passenger YM	
Littlewood (1972)	Airlines	Single-Leg, 2-Fare	Mixed
Rothstein (1971)	Airlines	Overbooking	Stochastic
Smith, et al. (1992)	Airlines	Case Study of Yield Management	
Weatherford (1997)	Airlines/General	Prices as Decision Variables	Stochastic
Williamson (1988)	Airlines	Comparison of Solution Methods	
Ladany & Arbel (1991)	Cruise Lines	Optimal Number of Classes and Optimal Prices	Deterministic
Smith (1993)	Electric Utilities	Real-time Model	Stochastic
Bitran & Gilbert (1992)	Hotels	Uncertain Arrivals	Stochastic
Bitran & Mondschein (1995)	Hotels	Multiple Day Stays	Stochastic
Kimes (1989a)	Hotels/General	Overview	
Liberman & Yechiali (1978)	Hotels	Stochastic Cancellations	Stochastic
Orkin (1988)	Hotels	Overview	
Rothstein (1974)	Hotels	Overbooking	Stochastic
Paschalidis & Tsitsiklis (1998)	Internet Providers	Revenue Management and Welfare Maximization	Stochastic
Balakrishnan, et al. (1996)	Manufacturing	Allocation of Capacity to 2 Product Classes	Stochastic
Cheung (1998)	Manufacturing/ Retail	Time discount when Stockout is Expected	Stochastic
Federgruen & Heching (1999)	Manufacturing/ Retail	Pricing and Inventory w/ Replenishment	Stochastic
Ishii & Nose (1996)	Manufacturing/ Retail	2 Customer Types and Capacity Constraint	Stochastic
Moinzadeh & Ingene (1993)	Manufacturing	2 Goods: Immediate and Delayed Delivery	Stochastic
Weatherford & Pfeifer (1994)	Manufacturing	Value of Accepting Advance Orders	Stochastic
Campbell & Morlok (1994)	Railroads	Overview	
Strasser (1996)	Railroads	Overview	
Geraghty & Johnson (1997)	Rental Cars	Case Study	Mixed
Bitran & Mondschein (1997)	Retail	Periodic Pricing; Permanent Markdowns	Stochastic
Chakravarty & Martin (1989)	Retail	Discounts and Restock Frequency	Deterministic
Gallego et al. (1997)	Retail	Empirical Study	Stochastic/UB w/ Deterministic
Smith & Achabal (1998)	Retail	Clearance Markdown	Deterministic
Smith et al. (1998)	Retail	Planned Markdowns	Stochastic
Subrahmanyan et al. (1996)	Retail	Optimal Pricing and Inventory in Short Season	Stochastic

4 OVERVIEW OF YIELD MANAGEMENT

4.1 General Principles of Yield Management

American Airlines is well-known for having described yield management as: "selling the right seats to the right customers at the right prices."[6] It can also be described as the process of managing the sales of perishable assets by controlling price and inventory so as to maximize profit. Weatherford and Bodily (1992) propose the name of perishable asset revenue management (PARM) to describe yield management strategies, and define it to be "the optimal revenue management of perishable assets through price segmentation."

Yield management revolves around a tradeoff between the number of sales and the revenue generated by each sale. Ideally, of course, selling the maximum number of items (airline seats, hotel room days, etc.) at the maximum rate would generate the largest profit. However, this may not be feasible, since high prices reduce demand for the product or service. Yield management works to balance the average price paid and capacity utilization. Yield is generally defined as the yield per available inventory unit. For example, airlines might measure the revenue per available seat mile, and hotels might be interested in the revenue per available room.

Revenue management is performed in different ways depending on the industry. In some, particularly airlines and hotels, product inventory management and pricing are often considered distinct components of yield management strategy.[7] However, this may not be true in all industries where PARM techniques are practiced. In most cases, yield management is guided by an electronic system that tracks the current number of orders and rates. Many industries make use of rate classes (groups of classes are sometimes called "buckets") for market segmentation. Further implementation issues are discussed in later sections.

4.2 Characteristics of Industries

Although different industries may implement yield management in different ways, there are a number of characteristics common to industries where yield management is traditionally applicable. Some of the basic ones are outlined below.[8]

- *Limited capacity*: The capacity of the firm should be relatively limited--that is, with either a high cost of adding a capacity or a time lag before capacity can be added. It is not necessary to be entirely fixed (for example, the rental car agency can choose to add cars in a particular market), although it is common in many industries where yield management is applied. This characteristics may also be described as a "fixed number of product units".

[6] American Airlines 1987 Annual Report
[7] Airlines: Belobaba (1987), Hotels: Kimes (1989a)
[8] Characteristics and descriptions from Kimes (1989a) and Weatherford and Bodily (1992)

- *Ability to segment markets*: In the airline industry, the market is segmented into business and pleasure travelers. A company may have different marketing plans, different services, etc. that distinguish the different segments. Arbitrary price discrimination is not allowed, so the product or service should have some characteristic that distinguishes the product in different markets. In many cases, the time of purchase is used to distinguish the service. However, other mechanisms are also possible; for example, the *time of delivery* of a product may differentiate it. For example, in the airlines, tickets may be distinguished by location of seat (First Class, Business, Coach, etc.) or time of purchase.
- *Perishable inventory*: Historically, yield management techniques have been applied to services or products that perish after a specific date (for example, an airline seat is unavailable for sale after the plane leaves the ground). The assumption has been that if the product or service does not perish, traditional inventory-management approaches can be used.

  Examples of industries with perishable inventories are provided in Weatherford and Bodily (1992): seats for the theater or sporting event; space on any means of transportation or in lodging; electricity and other utilities; fashion or high technology goods; traffic on fiber optic lines, etc.

  However, it may be possible to flexible pricing policies to apply to products which do not actually perish after a specific date, particularly in manufacturing industries. Even if the product itself (such as a computer, a car, a case of soft drinks, etc.) does not perish, the capacity can be thought of as a perishable asset. Although the available capacity over time does not perish, the ability to produce a computer on a given day becomes unavailable after the day is completed. So capacity units become the perishable inventory or perishable asset.
- *Product sold in advance*: As described before, time of purchase is a characteristic often used to differentiate products or services. Advance purchasing also creates uncertainty in the decision process. Should a product or service be sold at the current rate, or should it be held until a later date (and possibly a higher purchase price)?
- *Fluctuating demand*: In applicable industries, demand should have variability. It may vary seasonally, weekly, daily, etc. Yield management can be used to smooth the demand variability, by increasing the price during periods of high demand and decreasing the price during periods of low demand. Demand smoothing may significantly impact business processes and has the ability to greatly reduce costs.

4.3 Impacts of Implementing Yield Management

4.3.1 Quantitative Impact

Although most companies and researchers agree that yield management has provided large benefits, very little literature has specifically studied the quantitative impact of implementing yield management techniques. Some evidence of the impact can be found in papers addressing models in a specific industry or a specific company, but some of this is anecdotal. Further evidence may be available from companies; most of this is not

currently published. The evidence that has been presented in the literature is outlined below.

Orkin (1988) suggests that hotels can benefit from adopting yield management systems. In particular, he claims that Hyatt Regency's average rate for all reservations increased after the adoption of yield management techniques. He also states that many Hilton hotels have set revenue records since instituting yield management.

American Airlines calculates huge benefits due to yield management and claims that yield management is "absolutely essential to profitable operations".[9] The airline quantifies the benefit at $1.4 billion over the three year period preceding the article, and they projected an annual revenue contribution of more than $500 million in following years. In the airline industry, improving yield management by solving small subproblems more efficiently can translate into a large benefit on the bottom line. In particular, the problem of overbooking illustrates this (see the section on the airline industry for further discussion). Belobaba (1987) reports that airlines may increase revenues 5 percent or more after adopting revenue management techniques.

Geraghty and Johnson (1997) credit revenue management techniques with saving National Car Rental from liquidation. They state that the initial implementation moved National Car Rental into the black, and a cutting-edge revenue management system increased revenues $56 million in the first year of operation.

4.3.2 Other Impacts

Not all of the effects of yield management are directly linked to changes in revenue--many of the effects may not be immediately apparent. Some of the benefits to implementing yield management are discussed below.

- *Better match of supply and demand*: With a flexible pricing system, a company can be more effective at matching supply and demand. This can result in a increase in revenue, and it can also reduce the amount of inventory stored (if the company sells products rather than services). Better matching of supply and demand may also mean that a company is able to offer their product or service at a lower price to the consumer.
- *More accurate demand information*: A yield management system may provide more demand information than was previously available. This may occur because of increased tracking of demand in the yield management system or because demand is obtained at several different prices. On those occasions when implementing yield management implies removing the middleman between a company and the consumers, then this may also result in increased accuracy of the demand information.
- *Demand smoothing*: Yield management results in demand smoothing, which may effect the most important indirect benefits. By changing prices, management is either increasing or decreasing demand to better match supply and capacity. Over time, the demand pattern will have less variability than

[9] Smith, Leimkuhler, & Darrow (1992)

without yield management. Smoother demand patterns in turn lead to lower production and labor costs (overtime labor may no longer be needed). The cost savings due to demand smoothing may be quite large.

- *Strategic planning*: Many times, advance purchase of products or services is offered to provide product distinguishability. Advance purchasing of the products or services means that management can plan strategically for the future.

However, there are also potential costs or disadvantages to instituting a yield management system.[10]

- Customer relations: To date, customers have largely accepted flexible pricing systems in the airlines, hotels, etc. However, they may be averse to accepting flexible pricing in other industries. Customer relations and education should be considered when thinking of implementing a yield management system.
- Learning Curve: There is a learning curve associated with instituting yield management techniques. Employees will need to be trained in the new system. Flexible pricing systems may also be more difficult to work with than previous systems simply because they are more complex, so it may be more difficult to set prices than before.
- Capital outlay: Many times, investing in an electronic system to track customer orders is necessary. This may require a capital outlay at the beginning of implementation.
- Changes in incentive/reward system: With the adoption of flexible pricing systems, traditional incentive reward systems may no longer work. New systems may have to be developed in industries or companies where sales incentives currently exist.

Although there are both advantages and disadvantages to implementing a yield management system, most experiences thus far suggest that it can have an enormous positive impact on a company. It is credited with increasing revenues and profits in many industries and saving some companies from extinction.

5 GENERAL IMPLEMENTATION ISSUES[11]

5.1 Yield Management Sub-Problems

Yield management situations comprise a number of related sub-problems. All of these must be considered for a successful implementation.

[10] Some of the managerial implication costs are from Kimes (1989a).

[11] Much of the information contained in the following section is summarized from Kimes (1989b), with a number of modifications and extensions.

5.1.1 Demand Estimation

Before implementing PARM techniques, a company needs to have some knowledge of demand patterns. In particular, knowledge about distribution of consumers among different rate classes is useful. For example, demand distribution among different rate classes in the airlines is often considered to be normally distributed.

However, information about demand within the rate classes is also needed. A company needs to be able to estimate consumers sensitivity to price changes, or the demand elasticities for the various products. These demand elasticities can (and often will be) different for consumers in different rate classes.

Diversions among different rate classes (i.e., consumers switching from one rate class to another to obtain a lower price) is also an area to be considered by advanced yield management models. In many cases, initial implementations do not consider diversions, as they greatly increase the complexity of PARM models.

Usually, demand estimation is based on historical data. In cases where rate classes have not previously existed, it may be possible to obtain demand information in other ways (such as surveys, other types of historical data, etc.)

Some demand models may account for distribution among different rate classes as well as demand elasticities. In particular, discrete choice demand models like the logit class allow for many characteristics of products (including price) to determine the number of consumers expected to buy a product. Historical data on demand elasticities within rate classes is not needed for discrete choice demand models of this nature.

5.1.2 Policies: Overbooking and Price Guarantees

Overbooking management techniques and the inclusion of overbooking policies in yield management models have been very important in the airlines industry (as well as other industries). Overbooking is used to obtain demand to fill seats held by customers who become "no-shows" or cancel purchase of a product. It is the management strategy of intentionally selling more product (or service) than is available. American Airlines estimates that a management strategy of only selling available capacity would lead to about 15 percent unsold seats on flights which are sold out.

To include this as part of a yield management system, a company would need to have an estimation on no-show customers (often obtained from historical data). Kimes (1989b) states that in many industries, cancellations are assumed to follow a binomial distribution. Much research is available on overbooking, particularly in the airline and hotel industries.

Companies implementing revenue management techniques may also want to consider whether or not "price guarantee" policies will be offered. In this situation, consumers are guaranteed that if the price of a product or service drops within a specified period of time, they will be refunded the difference. Currently, research does not indicate that any industries that have implemented revenue management techniques are routinely providing such a guarantee to customers. For example, if a consumer pays for a ticket in the airlines, a refund is not given if the price later drops.

5.1.3 Information System

With implementation of flexible pricing policies, issues of data availability and accuracy are even more important than before. Estimates obtained from data are driving changes in prices, so it is absolutely essential to have confidence in this area. Companies implementing revenue management must be willing to make a significant investment in this area.

5.2 Problem Solving Techniques

Kimes (1989b) categorizes the problem solving techniques in yield management into four classes: (1) mathematical programming, (2) economics-based methods, (3) threshold curves, and (4) expert systems.

Mathematical programming methods included such techniques as linear programming, probabilistic programming, dynamic programming, and network approaches. Although the mathematical programming methods generally produced better results than the other methods, computer limitations hindered their acceptance in practice. The size of the formulation was often too large to be a practical approach with the computers available at the time.

Economics-based techniques included the popular marginal revenue approach. For example, Belobaba (1987) developed an expected marginal seat revenue (EMSR) to address seat allocation in an environment like the airlines. Attempts were also made to combine mathematical programming techniques and economics-based techniques (Curry (1990)).

Threshold curves also were popular methods for solving yield management problems.[12] To create the curves, historical demand data must be collected. Means and standard deviations are used to generate acceptable levels of demand. If demand falls above or below various thresholds, rate classes may be opened or closed accordingly. Some researchers view threshold curves as a form of statistical control not designed to find optimal solutions.

Expert systems such as a neural network approach have also seen some attention as a possible solution technique for yield management problems; however, the techniques do not seem to have been widely implemented to date. Further discussion of each of the solution methods including the basic models as well as some analysis of results is available in Kimes (1989b). Some comparison among different methods was also performed by Williamson (1988). Unfortunately, a more recent comparison of solution methods and results based on current computer capability and better solutions to sub-problems does not appear to be available.

Within a particular technique, a solution may considered to be *static* or *dynamic*. With a static formulation, a problem is solved only once at the beginning of a time horizon. Dynamic solutions are solved again as more information becomes available.

[12] It is unknown how popular these techniques are currently.

Kimes indicates that in many dynamic formulations, the approach is simply to resolve the static problem with the additional information.

6 INDUSTRY SPECIFIC IMPLEMENTATION

6.1 Airlines

Smith, et al. (1992) describe in surprising detail the history and implementation of yield management at American Airlines, a company considered by many to be at the forefront of yield management techniques. As many airlines have similarly developed models and some have followed in American's footsteps, the description is taken to be representative of many airlines and is summarized below. However, it should be noted that this case study was published in 1992 and does not reflect changes in yield management instituted since that time.

There have been a number of milestones in the airline industry that have affected the ongoing process of implementing new yield management techniques. Among those are the introduction of super-saver discounts in the late 1970s and the deregulation of airline schedules and prices in 1979. The internet has provided more recent changes that affect yield management policies. Most of the airlines (including American) now offer last minute e-fares (electronic fares), in an effort to stimulate demand to fill flights which have sold fewer seats than expected.

In the airline industry, yield management problem formulations can be quite large due to the large numbers of flights, connecting cities, etc. In one day, an airline can experience as many as 50,000 fare changes. To make the problem more manageable, American Airlines actually solves three separate sub problems: overbooking, discount allocation, and traffic management. Smith, et al. describe the solution technique as a "nonlinear, stochastic, mixed integer mathematical program that requires data ... that are subject to frequent changes." In addition to the three main subproblems, the airlines must estimate various types of demand and develop performance measures for yield management systems.

Like most companies that have implemented revenue management methods, American Airlines utilizes a highly sophisticated electronic resource to automate many of the pricing and inventory decisions. At American, SABRE (semi-automated business research environment) has been the tool of choice. SABRE was initially implemented in 1966. American's later system for yield management, DINAMO (dynamic inventory and maintenance optimizer) was implemented in 1988.

6.1.1 Airline Sub-Problems

Overbooking

As has been described before, overbooking is an important element of yield management, particularly in the airlines. Overbooking allows the airlines to oversell seats, anticipating that some customers will either cancel or not show for their flight reservation. To solve this subproblem, Decision Technologies (of American Airlines) made use of overbooking

marginal revenue curves with constraints on minimum service level, etc. The service level constraints were incorporated using Lagrangian relaxation. The input probabilities are estimated either by exponential smoothing models or by passenger choice models. When the airlines only offered one rate for seats on a particular flight, the overbooking model solved the entire yield management problem.

Discount Allocation

Airlines first began to offer a variety of fares in the mid-1970s, beginning with only two fares (full and discount). At that time, a probabilistic decision tree was used to determine whether to accept orders at discount rates. Probabilities (such as the probability of receiving a full fare from a consumer instead of the discount fare) were estimated using exponential smoothing time-series techniques and, in some cases, subjective analysis.

When multiple fare types were incorporated, a decision tree alone became inadequate for solve the problem of how many discount fares to offer. With multiple fares, a near-optimal heuristic involving the intersection of marginal revenue curves is used to determine the number of seats to allocate to fare classes. Research of mathematical programming techniques is also ongoing.

Fare "nesting" has become increasingly important in determining the number of seats to offer with the introduction of multiple fare classes. Nesting is the process of allowing smaller subsets of seats to be available to lower fare customers than to higher fare customers. High revenue customers have access to more fare classes than low revenue customers do. This is to prevent a high fare class from selling out of all available seats yet seats are available for sale in a lower priced fare.

Traffic Management

In the aftermath of airline deregulation, yield management became much more complex because of the new hub and spoke airline system. The number of passengers with connections between their destinations (i.e., non-stop flights) increased from 10 percent to 66 percent in about a five year period. The increasing numbers of connections and possible itineraries for a given origin and destination meant that large numbers of different fares had to be considered simultaneously. Airlines began clustering fares into groups of similar priced fares called "buckets", and used these to determine allocation of seats. A dynamic programming algorithm is periodically used to index fares into appropriate buckets using variability measures, and a mixed-integer linear programming algorithm is used to determine nesting tables, which lead to the determination of seat allocation.

American Airlines discovered that while time series *estimations of passenger demand* were fairly accurate, they sometimes did not reflect the most recent changes in the market. Modeling of demand is now done through a passenger choice utility function based on such attributes as time, service, airline choice, price, restrictions on ticket, etc. The logit-choice model is used as the basis for the demand model.

Implementation of new systems such as yield management also require the development of *performance measures* to monitor improvements and flag potential

problems. American Airlines has developed a number of measures, including techniques to identify forecasting problems, ensure that fares are grouped in buckets appropriately, etc. In addition, the airlines created a modeling system to measure the performance of yield management in terms of revenue opportunity as well.[13]

6.1.2 Impact

As reported before, the implementation of yield management in the airlines had a significant impact on the way business was done, as well as a significant (positive) change in the bottom line. Smith, et al. quantify the benefits of yield management in very specific areas. First, they suggest that overbooking provided an increase in revenue of approximately $225 million in 1990 (which was also representative of other years). After the installation of the DINAMO system, the improved discount allocation led to an increase in revenue by over $100 million per year. Since DINAMO led to the automation of many tasks that were performed manually before, productivity increased by more than 30 percent between 1988 and 1990 (a value of $1 million per year).

The reported impact of yield management during the three years preceding the article's publication was calculated to be $1.4 billion. When compared with the profit of American Airlines during that same three year period ($892 million), it is possible to see that yield management can be a very powerful tool.

6.2 Rental Car Agencies

American Airlines embraced yield management from the beginning, and has in fact pushed the edge of new techniques throughout the history of yield management. This contrasts well with the case study of yield management at National Car Rental, where implementation was performed virtually immediately to save the company and catch the rest of the industry. Geraghty and Johnson (1997) tell the story of National Car Rental's salvation from certain demise, attributed to the power of yield management techniques implemented well. The description provides useful insight into yield management techniques implemented in a different environment than the airline industry and some of the unique challenges faced.

6.2.1 Historical Background

In the early 90s, many of the car rental agencies were owned by auto manufacturers (General Motors owned National). Most companies, especially National, were dependent on corporate customers. Rental agreements did not include aspects such as prepayment or penalty fees for cancellations, both of which were common in the airline industry. No-shows were quite common for reservations of cars--sometimes more than 50 percent of reservations were no-shows! The rental agencies were also characterized by a busy mid-week season, and a mostly idle fleet on weekends.

[13] See Smith, et al. (1992) for full details on performance measures and other portions of implementation at American Airlines.

At National, price changes were manually performed and were quite time consuming. No single group or person was in charge of pricing decisions; rather, many groups had input and consequently price changes were not simple decisions. Fleet inventories were controlled locally without any system approach for advising. There were no demand forecasts for passenger rentals, either locally or at the corporate level. National discovered that competitors were raising prices closer to the date of rental, whereas National had a constant pricing policy. In addition, National was declining customer reservations even when cars were available.

To help develop a yield management system and implement it, National used Aeronomics Incorporated, who also worked with EDS information services provider on the project. They used a consulting company for outside expertise, as well as to overcome employee confusion and frustration with a new system. National allocated about $10 million to design and build the revenue management system. They also built a dedicated department with thirty specialists, all over a period of two years.

6.2.2 Specific Issues for the Industry

In some ways, yield management in the rental car industry is similar to yield management in the airlines. In particular, the problem of determining the appropriate number of seats per discount fares is comparable to upgrading a rental car reservation. In both cases, some overbooking may be performed, and reservation control is similar.

However, there are also some very important differences. One of the biggest issues in the rental car industry that does not exist in the airline industry is length of rental. This has implications for forecasting (need demand information on the number of days that customers will rent) as well as such areas as pricing (lowering the rate on one date affects rates on other dates).

Overbooking has greater consequences in the rental industry. Whereas in the airlines customers may fly in the next available flight for an incentive such as a free ticket, rental car customers are unlikely to accept such an arrangement. Forecast and planning accurately is very important during peak periods to avoid loss of sales due to overbooking.

Nesting issues are also different, since higher revenue customers are unwilling to accept the service offered to lower revenue customers (i.e., small cars). National determined the best solution was to have a larger fleet available.

Since local branches of rental car agencies have more control than local branches of the airlines, the issue of whether to centralize yield management decisions also became important at National. Implementing yield management in a decentralized manner involved fewer changes from the current process, but there were problems such as training, inconsistent pricing, fleet location, etc. National chose to implement revenue management at the corporate level, with a dedicated group of trained specialists. The revenue group became accountable for both inventory and pricing responsibilities.

6.2.3 Implementation Specifics

The revenue management system implemented at National combines capacity management, pricing, and reservation control. The pricing model uses a base rate for rental, and recommends an increase or decrease in rates based on the current number of cars rented for each arrival date. The model techniques used include mathematical programming to determine the minimum length of rental restrictions, Belobaba's (1989) EMSR heuristic for planned upgrades, a time series model with seasonality factors to forecast long term demand, and booking curves to aid in short term demand forecasting. Forecasting must be performed for the length of rental agreements as well as the expected number of cars rented at a particular point in time. Performance measures include such calculations as the lost demand (measured through turndown requests for rentals and "shoppers", who requested rates but chose not to rent).

National used several techniques to segment the market and differentiate their rental products. Some of these characteristics are advance purchase restrictions, different car types, different rates for weekends and weekdays, and planned upgrades. The advance purchase restrictions also avoids revenue dilution, the term used to describe the possible revenue lost to customers willing to pay a higher price but who received a lower price.

Geraghty and Johnson state that this system was the first in the rental car industry to combine all of the functions above, namely capacity management, pricing and reservation control. They estimate that revenues were improved by $56 million in the first year. The implementation of revenue management returned National to profitability and saved the company from liquidation.[14]

7 APPLICATION TO MANUFACTURING

Use of revenue management techniques has become widespread in several service and travel related industries. Even the retail industry has begun to see application of flexible pricing policies, particularly in the area of fashion clothing where markdown models have been applied over a selling season. However, few applications to date have dealt with implementing revenue management in a manufacturing environment. Examining implementations of yield management in other industries provides insights towards implementing them in manufacturing.

7.1 Similarities

In many ways, implementation of revenue management in a manufacturing industry is the same as in other industries. There are a number of necessary characteristics before a particular manufactured product may be considered as an application area for flexible

[14] For further details, see Geraghty and Johnson (1997).

pricing. The following section describes several important product or market characteristics.

7.1.1 Product or Market Characteristics

Fluctuating Demand
If demand does not fluctuate (and if the available supply does not significantly change), then it is possible to determine an fixed price that will maximize profit. However, if demand varies over time (daily, weekly, quarterly, etc.), then price can be used to match supply and demand. Revenue management will result in demand smoothing, which can have significant benefits for production costs. This characteristic is common for many types of manufactured products, including toys, cars, computers, air conditioners, etc. In fact, most products see some type of variable demand pattern.

Product Differentiation
A generalized definition of yield management (based on the one stated by American Airlines) is to "sell the right products to the right customers at the right prices". In most cases, a company is selling the same basic product to different customers at different prices, so it is essential to differentiate these products in some fashion.

Time is often used as a primary tool; for example, products may be purchased in advance like airline seats. Another option that applies more specifically to products instead of services is to have different delivery systems for products (e.g., different lead times).

Service may also be used to differentiate products (e.g., delivery to a residence instead of a common distribution center, or other types of premium service analogous to services in First Class on an airline). Premium service might include introducing customers to the operation of a product first hand, or issuing reminders about maintenance of the product, etc.

Refund policies may also be used to differentiate products; for example, expensive airline tickets generally have more lenient refund and exchange policies than more moderately priced tickets.

Market Segmentation
For a successful application of flexible pricing policies, it must be possible to segment the market in some way. In many cases, segmenting the market corresponds to the types of product differentiation offered. For example, many consumers may be sensitive towards time (e.g., they need a product as soon as possible). Others may be more sensitive towards price; perhaps these are willing to wait for a delayed delivery.

"Early adopters" also are a potential market segment—these consumers are interested in obtaining the very newest product in the market. Another market group comprises consumers who like to custom order products rather than

choosing from available inventory. Clear market segmentations and differentiated products avoid "revenue dilution", the situation in which consumers who would have paid a higher price divert to a lower priced product when it is available. There are many types of market segments to consider; successful implementations of revenue management methods will clearly define pertinent segments and match product characteristics with the consumer groups.

7.1.2 Common Processes and Needs

In addition to common product characteristics, the yield management process may have common attributes or needs in service and manufacturing industries. Some of these are outlined below.

- *Use price to better match supply and demand*
  This is the basic idea behind yield management, and it holds true in product oriented environments as well as service industries. Allow price to increase and decrease in response to either changes in demand or changes in supply to maximize profit. If necessary to reduce complexity, this may be done initially with prices as predetermined inputs and later extended to allow prices as decision variables.
- *Group customers in "rate classes"*
  Many of the service industries that have implemented revenue management use rate classes to group consumers. In most cases, they began with as few as two and later added more rate classes. The rate classes may be generated from the product differentiation characteristics. For example, if delivery time or custom ordering are used to distinguish products, two classes could represent customers who receive a product from inventory and customers who receive a custom order at a later time.
- *Invest in an information system*
  A good information system will be required to track the current status of the system, including orders placed, orders filled, scheduling considerations, etc. The system will also provide information about consumer demand.
- *Forecast demand accurately*
  Accurate assessments of demand are very important in yield management systems. There are many types of demand models and estimation techniques that can be chosen depending on the product and market. Examples from the literature include normally distributed demand, linear demand curves, logit demand models, etc. It may also be desired to incorporate demand diverting among various rate classes.
- *Determine Price and Ordering Policies*
  Industries that have already implemented revenue management have determined appropriate price and ordering policies for their needs. Policies will need to be determined on a variety of issues. Among these are questions such as the following: Are refunds, exchanges, or returns allowed? Will customers be guaranteed the lowest price in a particular time period? Should

customers pay the full amount or a deposit? Should the payment be made when the order is placed or when the product is delivered? If refunds or "no-shows" begin will occur, will the manufacturer use overbooking techniques? What will be the penalty paid to customers if a product is not available when promised?

- *Develop performance measures*
  With the implementation of a revenue management system, it will also be beneficial to incorporate performance measures to monitor improvements or failings in the system. Smith, et al. (1992) describe some of those used at American Airlines such as "revenue opportunity", which is the revenue that could have been generated under perfect information. Some performance measures will be particular to manufacturing (e.g., change in production costs under the new system).
- *Employ various problem solving techniques*
  In particular the case studies of revenue management implementation have shown that many types of techniques have been used to solve sub-problems. Examples include dynamic programming, mathematical programming (integer, mixed integer, linear, etc.), and marginal revenue curves. In many cases the implementing revenue management requires solving a number of sub-problems.

7.2 Differences

There are some very important differences between service and manufacturing industries concerning implementation of flexible pricing policies. The most important of these are outlined below.

7.2.1 Non-perishable Inventory

In all of the revenue management implementations to date, it has been assumed that inventory is non-perishable. That is, there is a specific date after which the inventory either ceases to exist or is discarded. Although this may not seem to be true of the retail fashion industry, in fact clothing is considered "useless" at the end of a short selling season. This characteristic will not hold in traditional ways in most manufacturing industries.

A manufacturing company may often carry inventory between periods. In contrast with many retail situations with perishable inventory, the inventory is usually not restricted to be non-increasing. In a manufacturing environment, the inventory itself is generally non-perishable, but the ability to produce a product may considered to be perishable (i.e., if capacity is unutilized today, that capacity is not available tomorrow). This allows manufacturing to fall under the Weatherford and Bodily (1992) definition of "perishable asset revenue management".

Since inventory will often be transferred between time periods, revenue management techniques must answer a number of questions not considered in the service

industries. For example, when and how much inventory should be kept on hand? Carrying inventory incurs holding costs, but customers may pay a higher price if product is available immediately—revenue management must balance these tradeoffs. If inventory is going to be kept, which products should be made? Accurate demand forecasts can help determine good solutions to this question as well. Revenue management can serve to increase or decrease the inventory, depending on whether it is more valuable to have product ready for immediate delivery, how much value customers place on custom orders, the production costs saved by producing ahead, etc.

7.2.2 Production and Capacity

Very closely linked with the issue of inventory will be production and capacity decisions. In most yield management situations, capacity is generally fixed (railroads and rental cars are two exceptions to this). This may not be true in a manufacturing environment, as capacity is sometimes a flexible parameter. In addition, allocations of capacity and production will need to be made among the different products that the company offers. Manufacturing companies will need to develop ways to schedule orders as they arrive if they do not do so already.

Production costs offer another area in which flexible pricing policies may provide benefits. As demand is smoothed over time, production schedules will also become smoother. A decrease in variability can lead to significant cost savings in the supply chain (such as labor costs). Revenue management may try to balance the cost savings achieved through demand smoothing with the discount offered customers to order in advance.

7.3 Additional Considerations

In addition to the clear-cut differences outlined above, other areas or questions will need to be considered. One of the characteristics in industries using flexible pricing policies is that most of them have high fixed costs and a low marginal cost for additional products or services. For manufacturing companies, this may not be true—there may be a moderately high marginal cost to producing an additional item.

The consumer market will also need to be considered. In additional to being segmentable, the consumers should have the appropriate sensitivity to price changes and product differentiation characteristics. If all of the consumers have high sensitivity to price, then they will purchase the product at the lower price and revenue will be less than before the implementation of yield management. If their sensitivity is too low, then the desired benefits (such as reduced production costs) may not be obtained. Clearly defining desired market segments and product differentiation characteristics will help ensure the success of revenue management.

By using flexible pricing policy techniques, companies may be able to increase the total number of products sold (using the previously unutilized capacity), rather than just selling the same number of products as before. This is the ideal situation, as it will lead to increased market size and increased profits.

Companies are turning to new business strategies to increase profits in an increasingly competitive world. The manufacturing industry can employ flexible pricing policies traditionally used in the service industries to bring about greater revenues and reduced costs. This integration of pricing and inventory control strategies will better match supply and demand and lead to increased profits. The companies that adopt these strategies and develop new ones will continue to be at the forefront of the global competitive market.

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