

# COORDINATION OF PRICING AND PRODUCTION-SCHEDULING DECISIONS IN SUPPLY CHAINS

A THESIS  
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MASTER OF SCIENCE

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September, 2008

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# Abstract

## COORDINATION OF PRICING AND PRODUCTION-SCHEDULING DECISIONS IN SUPPLY CHAINS

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Integration of various business functions ranging from procurement and distribution activities to customer relations has gained importance due to the progressively increasing global and domestic competitive pressures. As a consequence, many firms have set out to design, develop, and install their supply chain solutions.

The existing literature on wholesale price contracts takes into account the ordering and inventory holding component of the total. However, the impact of capacity considerations is overlooked in the coordination of replenishment decisions.

In this thesis, our objective is to synchronize the production planning and pricing decisions in buyer-vendor systems. In order to achieve this objective, the vendor quotes a price schedule that is a function of delivery time and order quantity. This price schedule stimulates the manipulation of buyer's order time and quantities so as to minimize vendor's total costs without changing the buyers' profit position.

**Keywords:** supply chain, pricing, production planning, price menu, coordination

# Özet

## TEDARİK ZİNCİRLERİNDE FİYATLANDIRMA VE ÜRETİM-PLANLAMA KARARLARININ KOORDİNASYONU

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Giderek ağırlaşan iç ve dış rekabet koşulları firmaların satın alma faliyetlerinden, ürünlerinin dağıtımına ve müşteri ilişkilerine kadar olan iş süreçlerinin entegrasyonunu zorunlu hale getirmiştir. Bu yüzden günümüzde çok sayıda firma tedarik zinciri yönetimi sistemlerini kurmaya başlamışlardır. Ancak bu konuda çok gelişmiş ve her sektörün ihtiyacını karşılayan maliyet etkin çözümlerinin olmayışı önemli bir eksiklik olarak ortaya çıkmaktadır.

Bu konu ile ilgili geçmişte yapılan bilimsel çalışmalar, alıcı ve satıcı arasındaki ticari ilişkinin koordinasyonunu sipariş verme ve envanter tutma maliyetleri çerçevesinde ele almakla beraber, satıcı firmanın olası kapasite kısıtlarını göz ardı etmektedir.

Biz bu tezde tedarikçi ve müşteri arasındaki koordinasyonun sağlanmasında önemli bir etken olan üretim planlama ve fiyatlandırma kararlarını sistematik bir yaklaşımla karar sürecine dahil etmeyi amaçlıyoruz. Bu sistematik yaklaşımın temelinde yatan düşünce, tedarikçi firmanın miktara dayalı fiyat politikasını belirlerken, müşterilerden gelecek sipariş profilini kendi üretim maliyetlerini azaltacak yönde etkilemesidir. İstenen etkinin gerçekleşmesi için belirlenen fiyat politikası, müşterilerin yeni talep profilleri sonunda olacak kar durumlarını azaltmamalıdır.

**Anahtar Kelimeler:** tedarik zinciri, üretim planlama, fiyatlandırma, fiyat menüsü, koordinasyon

*To my family,*

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# Chapter 1

## INTRODUCTION

Supply chain management is a relatively new area in manufacturing and service operations management. The need for managing the materials and information across the supply chain originates from the fact that the actions taken by one member of the chain can influence the profitability of the others. It has been shown in various studies that significant savings can be achieved due to coordinating the independently made decisions of the parties in supply chain systems. Therefore, many firms have set out to design, develop, and install their supply chain solutions to cope with the increasing global and domestic competitive pressures. The investment on supply chain optimization amounts to a scale of three million dollars in Turkey and to one billion dollar around the world. This indicates a need and an opportunity for the development of effective decision-support tools for supply chain management.

The evolution of supply chain management initiates from the classical multi-echelon inventory theory. The studies on multi-echelon inventory systems (e.g., Clark and Scarf (1960), Federgruen and Zipkin (1984),) suggest that the companies make their inventory replenishment decisions jointly. The major pursuit of the more recent studies is to introduce certain mechanisms into supply chain systems for aligning the individual incentives of the companies with the system performance, while still allowing independent decision making. In view of this trend, much of the recent research effort on supply chain management has

been spent to develop mechanisms for coordinating the system and to evaluate their effectiveness in different settings.

As it will be discussed in detail in the following section, a majority of the studies that could fall into this second body of research, takes minimization of inventory related costs as a performance measure. Few studies appeared in the more recent literature on supply chain management which consider other supply chain functionalities in addition to inventory management. For example, Toptal and Çetinkaya (2006) investigate the contractual agreements for supply chain coordination under the consideration of the vendor's inbound and outbound transportation costs.

In addition to inventory holding and transportation, another important function that affects supply chain costs significantly, is production scheduling. It is important to note that, the above mentioned literature overlooks production capacity and scheduling considerations at the vendor/manufacturer. However, in real life, a manufacturer may accept/reject orders on the basis of capacity constraints and he/she may quote varying wholesale prices for orders with different due-dates depending on resource availability. Better yet, he/she may adjust the wholesale prices to change the ordering behaviors of the buyers/retailers for increasing supply chain efficacy through better utilization of the capacity. This, in fact, is the opportunity at stake, which also, is the motivation to our study.

In this thesis, a single period, stochastic demand environment with one vendor/manufacturer and multiple buyers/retailers is considered, and the production capacity at the vendor<sup>1</sup> is modeled explicitly. The vendor's manufacturing plant is regarded as a single machine, and his/her earliness and tardiness costs resulting from the aggregate scheduling decisions are taken into account in computing his/her expected profits. The main objective of the thesis is

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<sup>1</sup> In the remaining parts of the thesis, "vendor" and "manufacturer", and "buyer" and "retailer" will be used interchangeably.

the design of contracts between the vendor and the buyers under careful consideration of the vendor's production capacity. To achieve this objective, a novel contract type is proposed and is compared to a more traditional one. The proposed contract allows the vendor to offer delivery time dependent wholesale prices to the retailers. The vendor considers the production capacity and scheduling decisions explicitly in determining the wholesale prices, and plans to deliver all accepted orders on time. Furthermore, the models constructed for this contract, enable the computation of wholesale prices which maximize the vendor's net profits while maintaining the buyers' potential profits that would result from their independent decisions. Then, the proposed contract type is compared to a more traditional one which allows the vendor to complete and deliver the accepted orders later than their promised duedates, while making a fixed payment (i.e., penalty cost) to the related retailer(s) in compensation. In this contractual agreement, wholesale prices do not depend on delivery times. Through an extensive numerical analysis, it is shown that considerable savings can be achieved by the proposed contractual agreement.

The organization of the thesis will be as follows. In the next chapter, a review of the literature is provided. In Chapter 3, the two contractual agreements are formulated, and the manufacturer's and the retailers' profit functions in each contract are derived. The following chapter analyzes the manufacturer's profit maximization problem in the proposed contract. Chapter 5 presents the experimental design and discusses the numerical results. Finally, in Chapter 6, general conclusions of this study are summarized.

# Chapter 2

## LITERATURE REVIEW

This study is closely related to the body of work on multi-echelon inventories, supply chain management and contracting theory. Optimization of serial inventory systems, i.e., multi-echelon inventories, dates back to 1960s with the pioneering work of Clark and Scarf (1960) for a stochastic demand environment. Following this study, numerous other researchers investigated the problem under different assumptions (e.g., Federgruen and Zipkin (1984), Debordt and Graves (1985), Rosling (1985)). Federgruen (1993) provides an excellent review of the literature on multi-echelon inventories. A common property of all the studies in this review paper is that, they model a decision-making system in which the suppliers and the retailers make their inventory and production decisions jointly, in a centralized manner. However, in real life, the implementation of a centralized model is very difficult unless the companies belong to the same corporation, or the vendor manages and owns the inventory at the buyer(s) as in a VMI (Vendor Managed Inventory) system. Çetinkaya and Lee (2000), Toptal et al. (2003) are some examples of recent papers that study the coordination problem in VMIs.

An alternative approach to the centralized modeling is the decentralized modeling, in which the supply chain players make their decisions on their own, with limited information sharing. However, it is known that the decentralized modeling approach results in a reduction of total system profits relative to the centralized modeling approach. In other words, the independent action of one

member of the supply chain may make others worse. This concept is referred to as “Double Marginalization” (Spengler, 1950) in the literature. One of the earlier studies in operations management which illustrate the gap between the two modeling approaches, is by Goyal (1976). Starting from this work, there has been an increasing trend in supply chain studies to investigate ways for improving the outcome of the decentralized model for a system, by using the corresponding centralized model as a benchmark. The idea of aligning the individual incentives for all parties in a decentralized model with those of the centralized solution is known as *channel coordination* in the literature. This is done by manipulating the system parameters such as wholesale price, salvage value etc., a.k.a., *coordination mechanisms*. The values of the system parameters involved in the coordination mechanisms are determined either by the supplier(s) or retailer(s) depending on who initiates coordination, and they are formalized in a contract.

There are many coordination mechanisms whose applicability depends on the supply chain characteristics, e.g., deterministic versus stochastic demand, the relationship between demand and wholesale price. Some examples to the most common contractual agreement types are:

- i. Wholesale Price Contracts*
- ii. Sales Rebate Contracts*
- iii. Buyback Contracts*
- iv. Revenue Sharing Contracts*
- v. Quantity Discount Contracts*
- vi. Quantity Flexibility Contracts*

In a wholesale price contract, the supplier sets the wholesale price which does not differ with respect to purchasing quantities. Lariviere and Porteus (2001), Cachon (2004), Bresnahan and Reis (1985) are examples of papers that study wholesale price contracts in a single-retailer, single-vendor system. While the former two studies are concerned with single period stochastic demand

environment, Bresnahan and Reis (1985) consider a deterministic demand setting. The design and implementation of wholesale price contracts in the presence of multiple retailers exhibits certain challenges. This is mostly due to the fact that price differentiation is prohibited in many countries by legislation, e.g., the Robinson-Patman Act in USA. Wang and Gerchak (2001) analyzes wholesale price contracts when there are multiple retailers.

In a sales rebate contract, a retailer pays the wholesale price set by supplier but then the supplier gives the retailer some amount for each unit sold above a threshold value. This contract form is studied by Taylor (2000a) and Krishman et al. (2001). Both papers focus on the coordination in the presence of retail effort. More specifically, a retailer can increase the demand for a product by lowering the retail price, but there are other ways to do this such as hiring more sales people, providing more training to current sales people, investing more in advertising or making the stores more attractive to customers etc. Such retail effort is mostly very costly to retailers. In this regard, Taylor (2000a) and Krishman et al. (2001) allow the retailer to exert effort to increase demand. In particular, Taylor (2000a) focuses on simultaneous decision effort and order quantity, whereas in Krishnan et al. (2001) an order quantity is first chosen and then effort level is decided after a signal of demand.

In a buyback contract, a retailer purchases each unit at a given wholesale price, and if there are some unsold items at the retailer at the end of the selling season, the supplier buys back some amount of the remaining quantity at a lower value than the wholesale price. The studies on buyback contracts consider several issues such as price policies, competition among retailers and retailer sales effort to make the system coordinated (e.g., Pasternack (1985), Emmons and Gilbert (1998), Padmanabhan and Png (1997), Taylor (2000a)).

In a revenue sharing contract, a retailer pays a wholesale price for each unit purchased plus a percentage of the revenue based on actual sales. There are a few

studies on this contract type, the most comprehensive one is done by Cachon and Larivierre (2005). They consider a general supply chain model where demand can be either deterministic or stochastic. This study also takes into account the case when supplier sells to a fixed-price newsvendor or a price-setting newsvendor.

Another contract type to coordinate a supply chain system is quantity discount contracts. In this contract type, a price discount is offered for large order sizes. Quantity discount contracts were first introduced into the marketing literature by Jeuland and Shugan (1983). In the operations research literature, Monahan (1984) is a pioneering work. Several extensions of this work consider the same problem under different settings. Banerjee (1986), Lee and Rosenblatt (1986) are examples of studies in a single-vendor, single-retailer setting. Hoffman (2000) analyzes quantity discount contracts for a system with multiple heterogeneous retailers. All these studies that are reviewed until now within the context of quantity discounts, assume that demand is independent of the retail price. Weng (1995) shows that it is not possible to coordinate the system with a quantity discount contract when demand is a decreasing function of retail price. However, if the retailers accept to pay a fixed amount to the supplier, the system can be coordinated.

The last contract type is a quantity flexibility contract. In these contracts, the supplier sets a wholesale price and compensates the retailer for the losses that result from unsold goods. This contract type provides full protection to the retailer on a portion of its order whereas the buyback contract partially protects the retailer on its complete order. If the supplier did not compensate the retailer's cost per unit which is additional cost to supplier's production cost, then the retailer would be partially protected. This is referred to as a *backup agreement* (e.g., Eppen and Iyer (1997)). Tsay (1999) studies supply chain coordination with quantity flexibility contracts and identifies the inefficiencies resulting from demand uncertainty. Quantity flexibility contracts are also studied in more complex settings including

multiple locations, multiple demand periods, lead times and demand forecast updates (e.g., Tsay and Lovejoy (1999)).

In addition to these six contract types, there are other studies in supply chain coordination, which consider price dependent demand (e.g., Bernstein and Federgruen (2000)), effort dependent demand (e.g., Netessine and Rudi (2000a), Gerchak (2001), and Gilbert and Cvsa (2000)), and demand updating (e.g., Donohue (2000), Mieghem (1999)).

Many of the studies reviewed above assume *information symmetry*, that is, both parties are aware of the knowledge about the system operations and parameters. An issue that has been recently addressed in the contracting literature is *information asymmetry*. As examples, see Corbett and Groote (2000), Ha (2001).

It is important to note that although there is a growing body of research that analyzes the effectiveness of different contractual agreements under various conditions, there is no study that integrates the scheduling decisions with supply chain coordination. Charnsirisakskul et al. (2005) is the most related paper to our research. They study a supply chain consisting of a manufacturer and multiple retailers. Each retailer is quoted a wholesale price determined by the size of order. After collecting all orders, the manufacturer solves an optimization problem under capacity constraints. The output provides the manufacturer with the information of which orders are accepted, the production schedule and delivery times of the orders. Although this research is quite similar to our study, its main focus is on the benefits of leadtime flexibility under capacity constrained production by quoting different prices for different order sizes. In addition, there is no consideration for supply chain coordination and no mechanism is proposed to guide the manufacturer to achieve this objective. Thus, our research will provide a contribution to fill this gap in the literature.

# Chapter 3

## PROBLEM FORMULATION

This research considers a decentralized two-stage supply chain consisting of a manufacturer and multiple retailers. The products that retailers order from the manufacturer are alike and require the same resources at the manufacturer's site. There is a single period of finite length, i.e. the *demand period* illustrated in Figure-1, during which random amounts of demand appear for the products. A retailer may have more than one product type to order. For the sake of generality, we use an index  $i$  ( $i=1,2,\dots,N$ ) to refer to a specific order, which is identified by its retailer and the product type jointly. The manufacturer announces the wholesale prices and the retailers decide on the optimal order quantities to maximize their expected profits. If the order quantity is not enough to satisfy the demand, then a retailer incurs a shortage cost per unsatisfied demand. If it is more than the demand, excess items are salvaged at a constant value per unit. The manufacturer has a finite *production period*, during which he/she has to produce the orders. Due to the limited production capacity, the manufacturer has the liberty of rejecting some orders. Transportation cost and time from the manufacturer to any of the retailers are negligible. Similarly, there is no cost or time spent by the manufacturer for production setups.

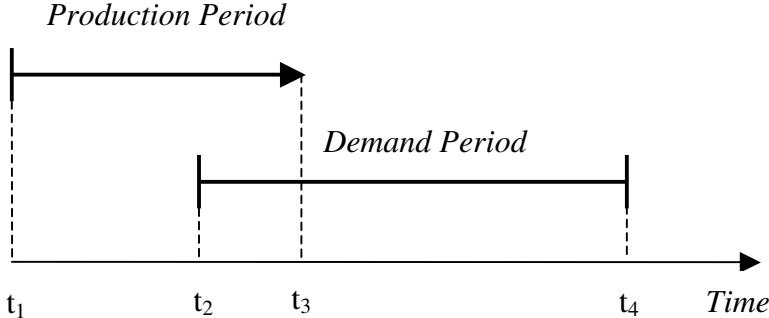


Figure 1: Production and Demand Periods ( $t_1 \leq t_2 < t_3 < t_4$ )

For this system, we propose a new contractual agreement that may increase manufacturers' profits through a better utilization of his/her capacity. This is achieved by integration of the manufacturer's pricing and scheduling decisions. More specifically, the manufacturer offers a delivery time dependent wholesale price for each product type, which changes the retailers' ordering behavior in such a way that the manufacturer's production schedule is improved. We refer to this contract as *delivery-date-dependent pricing (DTDP)*. We compare this type of contractual agreement to a more traditional one that we refer to as *fixed wholesale pricing with tardiness penalty (FWPT)*. As the name implies, in this contract, the announced wholesale price by the manufacturer is constant regardless of the delivery time. If a delay occurs in the delivery time, a tardiness penalty is paid by the manufacturer at a predetermined rate per unit per unit time of delay.

Under these considerations, we next present a detailed description of the two contract types.

**Contract FWPT:**

- The manufacturer announces the wholesale prices before his/her production period begins. Wholesale prices are fixed and do not depend on order quantities or delivery times.

- Retailers decide on their optimal order quantities as if their orders will be delivered before the demand period begins.
- When all orders are received, the manufacturer accepts the ones that jointly maximize his/her profit under a limited production capacity.
- All accepted orders are quoted a delivery time of  $t_2$ . However, if an order is delivered to its retailer after time  $t_2$ ,  $\$S_i$  per unit is paid by the manufacturer for each unit time of delay.

It is important to note that, in this type of contract, the actual delivery time of an order may be different from the quoted delivery time. Furthermore, in case the manufacturer delays the delivery of an order, its quantity does not change and is given by the retailer's expected profit maximizer in period  $[t_2, t_4]$ .

**Contract *DTDP*:**

- The manufacturer announces the wholesale prices before the production period, however different prices are quoted for different delivery times of an order.
- Each retailer evaluates the *wholesale price, delivery time* information and chooses a pair that maximizes his/her expected profits.
- Due to his/her limited production capacity, a manufacturer may again reject some of the orders.
- All accepted orders must be delivered no later than their quoted delivery times.

In the setting that is of interest in this paper, we assume that the manufacturer has full information about the demand process and the cost parameters of each retailer. Under this assumption, Contract *DTDP* allows the manufacturer to come up with a price schedule that implicitly forces a retailer to choose a *wholesale*

*price, delivery time* pair that increases the manufacturer's profits while keeping the retailer satisfied. For modeling this type of a contract, we assume that there are  $K + 1$  different delivery dates that a manufacturer can quote to a retailer within the production period. We index the delivery dates by  $k$  (i.e.,  $d_k$ ) where  $k = 0$  refers to the start time of the manufacturer's production period. We assume that the demand for order  $i$  from time  $d_k$  to the end of the demand period has a probability distribution with mean of  $\mu_i^k$  and standard deviation of  $\sigma_i^k$ . Note that, in Contract *FWPT*,  $K = 0$  and  $d_0 = t_2$ .

In Contract *DTDP*, a retailer decides the delivery time of an order among a menu of *wholesale price, delivery time* pairs, and the manufacturer delivers an accepted order no later than that time. Therefore, a retailer who chooses a delivery date  $d_k$  such that  $d_k > t_2$ , takes into account the expected demand lost until  $d_k$ , and thereby, the new demand process with parameters  $\mu_i^k$  and  $\sigma_i^k$ .

Before analyzing the manufacturer's and the retailers' expected profits resulting from the two contract types, we summarize below the notation introduced so far and that will be used throughout the paper.

$r_i$  : Retail price per unit of Order  $i$ .

$Q$  : Quantity of an order.

$X$  : Random variable showing total demand at a retailer.

$w$  : Wholesale price.

$\bar{w}_i$  : Market price for one unit of Order  $i$ .

$f_i^k(\cdot)$  : Probability density function of demand for order  $i$  from time  $d_k$  to the end of the demand period.

$F_i^k(\cdot)$  : Probability distribution function of demand for order  $i$  from time  $d_k$  to the end of the demand period.

$(w_{ij}, d_{ij})$  : A wholesale price, delivery time pair for the  $i^{\text{th}}$  retailer. Here,  $j$  is the index of the pair.

$b_i$  : Lost sale cost/unit of Order  $i$ .

$g_i$  : Salvage value/unit of Order  $i$ .

$h_i$  : Inventory cost of the manufacturer for holding one unit of Order  $i$  for a unit time.

$S_i$  : Tardiness cost paid by the manufacturer for a unit time delay of Order  $i$ .

$p_i$  : Manufacturer's processing time per unit of Order  $i$ .

$c_i$  : Manufacturer's production cost per unit of Order  $i$ .

$d_k$  : Value of delivery date  $k$  ( $d_0 = t_2$ ).

$\vartheta$  : Contractual agreement type (*FWPT* or *DTDP*).

$C$  : Completion time of an order.

$T$  : Length of the manufacturer's production period.

$\Pi_i^\vartheta(Q, w, C)$  : Expected profits of the retailer for Order  $i$  in Contract  $\vartheta$ .

$\Psi_i^\vartheta(Q, w, C)$  : Manufacturer's profits from Order  $i$  in Contract  $\vartheta$ .

$\Theta_i^\vartheta(Q, C)$  : Tardiness penalty paid by the manufacturer for Order  $i$  in Contract  $\vartheta$ .

The tardiness penalty paid by the manufacturer for Order  $i$  in Contract *FWPT* is

$$\Theta_i^{\text{FWPT}}(Q, C) = \begin{cases} (C - t_2) S_i Q & \text{eğer } C \geq t_2 \\ 0 & \text{aksi takdirde} \end{cases} \quad (1)$$

Recall that in Contract *DTDP*, there is no tardiness cost. Therefore, we have

$$\Theta_i^{\text{DTDP}}(Q, C) = 0. \quad (2)$$

The expected profit of the retailer who places Order  $i$  is then given by

$$\Pi_i^\vartheta(Q, w, C) = (r_i - g_i) \mu_i^k - (w - g_i) Q - (r_i - g_i + b_i) \int_Q^\infty (x - Q) f_i^k(x) dx + \Theta_i^\vartheta(Q, C) \quad (3)$$

where  $k = \arg \min \{k : C \leq d_k, k \in \{0, 1, \dots, K\}\}$ . The above expression is based on the following two assumptions: (i) the manufacturer delivers an order as soon as it is completed, (ii) the closest delivery time available larger than the planned completion time is quoted to the retailer. Notice that, these assumptions lead to the fact that, in Contract *DTDP*, the expectation of the retailer in terms of his/her profit for Order  $i$  is independent of the actual completion time as long as different completion times result in the same delivery date. That is, we have  $\Pi_i^{DTDP}(Q, w, C_1) = \Pi_i^{DTDP}(Q, w, C_2)$ , where  $d_{k-1} < C_1 \leq d_k$ ,  $d_{k-1} < C_2 \leq d_k$  and  $C_1 \neq C_2$ . On the other hand, Contract *FWPT* implies that  $\Pi_i^{FWPT}(Q, w, C_2) > \Pi_i^{FWPT}(Q, w, C_1)$  for  $k \geq 1$ . That is, under the assumption that the demand distribution does not change from  $C_1$  to  $C_2$ , in Contract *FWPT*, the retailer is better off if his/her tardy-to-be order is delayed further. More specifically, depending on the lost sales cost and the value of tardiness cost, there may be cases where a retailer may increase his/her profits due to delayed orders.

The manufacturer's profit from Order  $i$  in both of the contracts is

$$\Psi_i^\vartheta(Q, w, C) = Q(w - c_i) - \frac{Q(Q+1)h_i p_i}{2} - \Theta_i^\vartheta(Q, C) \quad (4)$$

The manufacturer's inventory holding cost, which is the second term of Expression (4), utilizes the fact his/her optimal sequence in both contract types is non-preemptive. Also, inventory holding costs start to accumulate for a product in Order  $i$ , at a rate of  $\$ h_i$  per unit time, from the moment its processing begins until the whole order is completed.

In Contract *FWPT*, the retailer of Order  $i$  solves the following problem:

$$\begin{aligned} \max \quad & \Pi_i^{\text{FWTP}}(Q, \bar{w}_i, t_2) \\ \text{s.t.} \quad & Q \in \{0\} \cup Z^+ \end{aligned}$$

where  $Z^+$  denotes the set of positive integers. Note that the optimal quantity that maximizes the expected profits of the retailer placing Order  $i$  (i.e.,  $Q_i^*$ ) is given by

$$Q_i^* = \min \left\{ Q \in \{0\} \cup Z^+ \mid F_i^0(Q) \geq \frac{r_i - \bar{w}_i + b_i}{r_i - g_i + b_i} \right\} \quad (5)$$

In Contract *DTDP*, the retailer of Order  $i$  is offered a menu of delivery dates with corresponding wholesale prices, and he/she chooses the pair that maximizes his/her expected profits as follows:

$$\begin{aligned} \max \quad & \Pi_i^{\text{DTDP}}(Q, w_{ij}, d_{ij}) \\ \text{s.t.} \quad & Q \in \{0\} \cup Z^+, \forall j \end{aligned}$$

In both of the contractual agreements, after the manufacturer receives the optimal order quantities for all orders, he/she prepares the production schedule. Due to his/her limited production capacity, the manufacturer may reject some of the orders. Recall that, in contract *DT DP*, the manufacturer offers a delivery time dependent price schedule before the orders are collected. This gives the manufacturer the opportunity to consider beforehand his/her scheduling decisions simultaneously with pricing decisions, and thereby, to increase his/her profits under limited capacity. In using pricing as a mechanism to change the ordering behaviors of the retailers, the manufacturer should put the expected profits of the accepted retailers no worse than what they would be under the market price with a delivery time  $t_2$ . That is, the expected profit for Order  $i$ , if it is accepted under Contract *DTDP*, should at least be equal to  $\Pi_i^{\text{FWTP}}(Q_i^*, \bar{w}_i, t_2)$ . Otherwise, the retailer who owns Order  $i$  may reject the business of the current manufacturer and may find alternative suppliers in the market. For a single order, there may be

several *wholesale price, delivery date* pairs (i.e.,  $(w_{ij}, d_{ij})$ ) that put the retailer's expected profits no worse than  $\Pi_i^{FWTP}(Q_i^*, \bar{w}_i, t_2)$ . Considering all such pairs over all orders, the manufacturer should choose a pair for each order such that when all retailers demand the optimal order quantities under those pairs, the manufacturer achieves the maximum profit under limited production capacity. Finally, the manufacturer prepares a menu of prices and delivery dates for each order. In order to model the manufacturer's perspective in Contract *DTDP*, we will follow the below steps:

- I. Finding  $(w_{ij}, d_{ij})$  pairs that put the retailer's expected profits no worse than  $\Pi_i^{FWTP}(Q_i^*, \bar{w}_i, t_2)$  for each Order  $i$ . The vector of all such pairs for Order  $i$  will be denoted by  $J_i$ . This step will be referred to as *Preparation of Wholesale Prices and Delivery Dates*.
- II. Among  $|J_i|$  number of pairs for Order  $i$ , finding the one those results in the maximum profit for the manufacturer with other orders, for all  $i$ . This step will be referred to as *Preparation of the Price Menu*.

Next, we will analyze these steps as parts of the manufacturer's sub-problem.

# Chapter 4

## Manufacturer's Subproblem in Contract *DTDP*

### 4.1 Preparation of Wholesale prices and Delivery Times

In this section, we present a search algorithm to identify  $(w_{ij}, d_{ij})$  pairs that put the retailer's expected profits no worse than  $\Pi_i^{FWTP}(Q_i^*, \bar{w}_i, t_2)$  for each Order  $i$ .

This search algorithm will utilize the following proposition and the remark.

**Proposition 1:** Let  $Q_1$  and  $Q_2$  be two order quantities that maximize the expected profits of a retailer for Order  $i$  for a given delivery date  $d_k$  at wholesale prices  $w_1$  and  $w_2$ , respectively. That is,  $Q_1$  satisfies  $F_i^k(Q_1) = \frac{r_i - w_1 + b_i}{r_i - g_i + b_i}$  and  $Q_2$  satisfies  $F_i^k(Q_2) = \frac{r_i - w_2 + b_i}{r_i - g_i + b_i}$ . If  $Q_2 > Q_1$ , then we have

$$\Pi_i^{DTDP}(Q_2, w_2, d_k) > \Pi_i^{DTDP}(Q_1, w_1, d_k), \forall k \in \{0, 1, \dots, K\}$$

**Proof:** Using Expression (3), we have

$$\Pi_i^{DTDP}(Q_1, w_1, d_k) = (r_i - g_i) \mu_i^k - (w_1 - g_i) Q_1 - (r_i - g_i + b_i) \int_{Q_1}^{\infty} (x - Q_1) f_i^k(x) dx \quad (6)$$

and

$$\Pi_i^{DTDP}(Q_2, w_2, d_k) = (r_i - g_i) \mu_i^k - (w_2 - g_i) Q_2 - (r_i - g_i + b_i) \int_{Q_2}^{\infty} (x - Q_2) f_i^k(x) dx \quad (7)$$

Plugging in  $w_1 = r_i + b_i - (r_i - g_i + b_i) F_i^k(Q_1)$  and

$w_2 = r_i + b_i - (r_i - g_i + b_i) F_i^k(Q_2)$  in Expressions (6) and (7), respectively, we have

$$\Pi_i^{DTDP}(Q_1, w_1, d_k) = (r_i - g_i) \mu_i^k - (r_i - g_i + b_i) \int_{Q_1}^{\infty} x f_i^k(x) dx$$

and

$$\Pi_i^{DTDP}(Q_2, w_2, d_k) = (r_i - g_i) \mu_i^k - (r_i - g_i + b_i) \int_{Q_2}^{\infty} x f_i^k(x) dx$$

Since  $Q_2 > Q_1$ , using the above two equations, it follows that

$$\Pi_i^{DTDP}(Q_2, w_2, d_k) > \Pi_i^{DTDP}(Q_1, w_1, d_k)$$

In order to form  $J_i$  for each Order  $i$ , we propose an algorithm that is based on a search procedure over  $Q$  for a given  $d_k$  over all  $k \in \{1, 2, \dots, K\}$ .

**Algorithm I:**

**(A1)** Start with the first delivery date (i.e.,  $t_2$ ) and set the index of the first pair to zero. That is,  $k = 0$  and  $j = 0$ .

**(A2)** For the current delivery date  $d_k$ , using Algorithm 2, find the smallest integer  $Q$  such that  $\Pi_i^{DTDP}(Q, w, d_k) \geq \Pi_i^{FWTP}(Q_i^*, \bar{w}_i, t_2)$  where  $w = r_i + b_i - (r_i - g_i + b_i) F_i^k(Q)$ . If none exists, go to Step (A4). Otherwise, set  $(w_{ij}, d_{ij}) = (w, d_k)$ ,  $m = \Psi_i^{FWTP}(Q, w, d_k)$  and  $j = j + 1$ .

**(A3)** Increase  $Q$  one by one and find the wholesale price at which  $Q$  is optimal, until the wholesale price falls below  $c_i$ . Add new pairs for quantities that increase the manufacturer's profits. That is,

1. Set  $Q = Q + 1$ .
2. Set  $w = r_i + b_i - (r_i - g_i + b_i) F_i^k(Q)$ .
3. If  $w \leq c_i$ , go to Step (A4).
4. If  $\Psi_i^{FWTP}(Q, w, d_k) > m$ , set  $(w_{ij}, d_{ij}) = (w, d_k)$ ,  $m = \Psi_i^{FWTP}(Q, w, d_k)$  and  $j = j + 1$ . Go to Step (A3).1.

**(A4)** Proceed with the next available delivery date. If there is none, stop the algorithm. That is,

1. If  $k < K$ , set  $k = k + 1$  and go to Step (A2).
2. Else, set  $|J_i| = j$  and stop the algorithm returning  $J_i$ .

**Algorithm II:**

**(B1)** If  $k = 0$ , stop and return  $Q = Q_i^*$ .

**(B2)** Compute the retailer's optimum order quantity at the market price assuming that the order is quoted a delivery date of  $d_k$ . That is, find the minimum

integer  $Q$  such that  $F_i^k(Q) \geq \frac{r_i - \bar{w}_i + b_i}{r_i - g_i + b_i}$ . If  $\prod_i^{DTDP}(Q, \bar{w}_i, d_k) \geq \prod_i^{FWTP}(Q_i^*, \bar{w}_i, t_2)$ ,

go to Step (B3). Else, go to Step (B4).

**(B3)** Decrease  $Q$  one by one until  $\prod_i^{DTDP}(Q, w, d_k) < \prod_i^{FWTP}(Q_i^*, \bar{w}_i, t_2)$  where  $w = r_i + b_i - (r_i - g_i + b_i) F_i^k(Q)$ , or  $Q = 1$ . If  $\prod_i^{DTDP}(Q, w, d_k) < \prod_i^{FWTP}(Q_i^*, \bar{w}_i, t_2)$  is reached first, stop and return  $Q + 1$ . If  $Q = 1$  is reached first, stop and return  $Q$ .

**(B4)** Increase  $Q$  one by one until  $\prod_i^{DTDP}(Q, w, d_k) \geq \prod_i^{FWTP}(Q_i^*, \bar{w}_i, t_2)$  or  $w < c_i$  where  $w = r_i + b_i - (r_i - g_i + b_i) F_i^k(Q)$ . If  $\prod_i^{DTDP}(Q, w, d_k) \geq \prod_i^{FWTP}(Q_i^*, \bar{w}_i, t_2)$  is reached first, stop and return  $Q$ . If  $w < c_i$  is reached first, stop and return null.

Algorithm I in conjunction with Algorithm II, provides the set  $J_i$  for a given order. Notice that, a *wholesale price, delivery date* pair within this set result in an expected profit of at least  $\Pi_i^{FWTP}(Q_i^*, \bar{w}_i, t_2)$ . Therefore, we assume any pair in this set is acceptable by the retailer of Order  $i$ . After the manufacturer finds all such pairs for all orders by running Algorithm I for  $i = 1, 2, \dots, N$ , he/she prepares the production schedule. In the next section, we present a model for the manufacturer to decide which orders he/she will accept, and what wholesale price and delivery date he/she will quote for accepted orders, while preparing his/her production schedule.

## 4.2 Preparation of Price Menu

In the previous section, we presented an algorithm for the manufacturer to find wholesale price values paired with delivery dates for an Order  $i$ , which put the ordering retailer in a no worse expected profits than  $\Pi_i^{FWTP}(Q_i^*, \bar{w}_i, t_2)$ . Next, we present an optimization model for the manufacturer to decide which orders to accept/reject, and the best *wholesale price, delivery date* pair for each accepted order that maximizes his/her expected profits under limited production capacity.

The decision variables in this optimization model are as follows:

$$y_{ij} = \begin{cases} 1 & \text{if } j^{\text{th}} \text{ pair is chosen for Order } i \\ 0 & \text{otherwise} \end{cases}$$

$$x_{ijlm} = \begin{cases} 1 & \text{if Order } i, \text{ for which } j^{\text{th}} \text{ pair is chosen, is scheduled before} \\ & \text{Order } i, \text{ for which } m^{\text{th}} \text{ pair is chosen} \\ 0 & \text{otherwise} \end{cases}$$

$$\alpha_{ij} = \begin{cases} 1 & \text{if Order } i \text{ for which } j^{\text{th}} \text{ pair is chosen, is completed after } d_{ij} \\ 0 & \text{otherwise} \end{cases}$$

$C_{ij}$  : Production finish time of production of Order  $i$  for  $j^{\text{th}}$  pair

The mathematical model presented below can be used to make the scheduling and order acceptance/rejection decisions in both contractual agreements. More specifically, for Contract *DTDP*,  $S_i$  is set to a very large number, and set  $J_i$  formed according to Algorithm I, is used for each order. For Contract *FWPT*,  $S_i$  is set to its value as it is determined by the manufacturer, and  $J_i$  only includes  $(\bar{w}_i, t_2)$ .

Before proceeding with the mathematical model, we define one more notation. Let  $k$  be the index of delivery date  $d_{ij}$ . For pair  $(w_{ij}, d_{ij})$ , we define  $Q_{ij}$  as follows:

$$Q_{ij} = \min \left\{ Q \in \{0\} \cup \mathbb{Z}^+ \mid F_i^k(Q) \geq \frac{r_i - w_{ij} + b_i}{r_i - g_i + b_i} \right\}$$

If the following model results in  $y_{ij} = 0$  for all pairs  $j$  in set  $J_i$ , this implies that Order  $i$  is rejected. Otherwise, it is accepted.

### **MODEL I :**

#### **Objective Function**

$$\begin{aligned} \max \sum_{i=1}^N \sum_{j=0}^{|J_i|} y_{ij} Q_{ij} (w_{ij} - c_i) - \sum_{i=1}^N \sum_{j=0}^{|J_i|} \frac{y_{ij} p_i h Q_{ij} (Q_{ij} + 1)}{2} \\ - \sum_{i=1}^N \sum_{j=0}^{|J_i|} y_{ij} \alpha_{ij} (C_{ij} - d_{ij}) Q_{ij} S_i \end{aligned} \quad (8)$$

#### **Constraints**

Don't exceed the total capacity

$$\sum_{i=1}^N \sum_{j=0}^{|J_i|} Q_{ij} p_i y_{ij} \leq T \quad (9)$$

Determine a wholesale price for accepted orders

$$\sum_{j=0}^{|J_i|} y_{ij} \leq 1 \quad \text{for all } i \quad (10)$$

Precedence relationships and capacity allocations

$$x_{ijlm} + x_{lmij} = 1 \quad \text{for all } (i,j) \text{ ve } (l,m) \text{ such that } (i,j) \neq (l,m) \quad (11)$$

$$C_{lm} - C_{ij} \geq Q_{lm} p_l x_{ijlm} - (1 - x_{ijlm}) M \quad \text{for all } (i,j) \text{ ve } (l,m) \text{ such that } (i,j) \neq (l,m) \quad (12)$$

Orders cannot be completed at time zero

$$C_{ij} \geq Q_{ij} p_i \quad \text{for all } (i,j) \quad (13)$$

Determine tardiness amounts

$$C_{ij} - d_{ij} \leq \alpha_{ij} M \quad \text{for all } (i,j) \quad (14)$$

Define range of decision variables

$$x_{ijlm} \in \{0,1\} \quad \text{for all } (i,j) \text{ ve } (l,m) \text{ such that } i \neq l \quad (15)$$

$$y_{ij} \in \{0,1\} \quad \text{for all } (i,j) \quad (16)$$

$$\alpha_{ij} \in \{0,1\} \quad \text{for all } (i,j) \quad (17)$$

The objective function in the above model includes the manufacturer's revenue from sales, inventory holding costs and tardiness costs for all orders that are accepted. Expression (9) guarantees that production capacity is not exceeded. Expression (10) ensures that if an order is accepted, a single *wholesale price, delivery date* pair is chosen for this order. Expressions (11) and (12) jointly determine the precedence relationships. Expression (13) eliminates zero completion times. Expression (14) determines which orders are tardy. Finally, Expressions (15), (16) and (17) define the range of decision variables.

It can be observed that the objective function in *MODEL I* is nonlinear. *MODEL II* that will be presented next, builds upon *MODEL I* and is linear. An additional decision variable that will be referred to as  $v_{ij}$  will be used in this model. We define  $v_{ij}$  as follows:

$v_{ij}$  : Tardiness amount for Order  $i$  if  $j^{\text{th}}$  pair is chosen for this order.

**MODEL II :**

**Objective Function**

$$\max \sum_{i=1}^N \sum_{j=0}^{|J_i|} y_{ij} Q_{ij} (w_{ij} - c_i) - \sum_{i=1}^N \sum_{j=0}^{|J_i|} \frac{y_{ij} p_i h_i Q_{ij} (Q_{ij} + 1)}{2} - \sum_{i=1}^N \sum_{j=0}^{|J_i|} Q_{ij} S_i v_{ij} \quad (18)$$

**Constraints**

Don't exceed the total capacity

$$\sum_{i=1}^N \sum_{j=0}^{|J_i|} Q_{ij} p_i y_{ij} \leq T \quad (19)$$

Determine a wholesale price for accepted orders

$$\sum_{j=0}^{|J_i|} y_{ij} \leq 1 \quad \text{for all } i \quad (20)$$

Precedence relationships and capacity allocations

$$x_{ijlm} + x_{lmij} = 1 \quad \text{for all } (i,j) \text{ ve } (l,m) \text{ such that } (i,j) \neq (l,m) \quad (21)$$

$$C_{lm} - C_{ij} \geq Q_{lm} p_l x_{ijlm} - (1 - x_{ijlm}) M \quad \text{for all } (i,j) \text{ and } (l,m) \text{ such that } (i,j) \neq (l,m) \quad (22)$$

Orders cannot be completed at time zero

$$C_{ij} \geq Q_{ij} p_i \quad \text{for all } (i,j) \quad (23)$$

Determine tardiness amounts

$$v_{ij} \leq y_{ij} M \quad \text{for all } (i,j) \quad (24)$$

$$v_{ij} \geq C_{ij} - d_{ij} - (1 - y_{ij}) M \quad \text{for all } (i,j) \quad (25)$$

Define range of decision variables

$$v_{ij} \geq 0 \quad \text{for all } (i,j) \quad (26)$$

$$x_{ijlm} \in \{0,1\} \quad \text{for all } (i,j) \text{ ve } (l,m) \text{ öyleki } i \neq l \quad (27)$$

$$y_{ij} \in \{0,1\} \quad \text{for all } (i,j) \quad (28)$$

The objective function in the above model includes the manufacturer's revenue from sales, inventory holding costs and tardiness costs for all orders that are accepted. Expression (19) guarantees that production capacity is not exceeded. Expression (20) ensures that if an order is accepted, a single *wholesale price, delivery date* pair is chosen for this order. Expressions (21) and (22) jointly determine the precedence relationships. Expression (23) eliminates zero completion times. Expression (24) and (25) determine which orders are tardy. Finally, Expressions (26), (27) and (28) define the range of decision variables.

We realize that, after some initial runs of MODEL-I for Contract *DTDP* even for identical retailers, this formulation permits us to solve small-scale problems. Fortunately, by reducing the number of variables we solve sufficiently large-scales optimization problems for identical retailers. To achieve this, we use the following two facts: (1) the sequence of production orders for a given latest delivery time does not change the total expected profit of the manufacturer as long as they are consecutively produced and (2) the process should be non-preemptive whenever the production of an order starts. For example, consider two delivery times and suppose half of the orders are promised to be shipped until first delivery time and the rest is until the second one. Furthermore, the manufacturer uses all its production capacity. All non-preemptive sequences ensuring that all orders are shipped prior their promised times result in same profit for the manufacturer. Notice that first fact follows from the fact that there is no tardiness cost in Contract *DTDP*.

Basically, the optimization model decides which orders are selected at what wholesale prices for each delivery times. The model achieves this by ensuring that for a given delivery time total used capacity does not exceed actual capacity and there is no late delivery until that time. Similar to previous models, new model

maximizes the total profit. For this model, we need to, in addition to previous notation, define the following parameters and decision variables.

### Parameter

$TC_k$  : Total actual capacity until  $k^{\text{th}}$  delivery time

### Decision variable

$$x_{ijk} = \begin{cases} 1 & \text{if order } i \text{ at } j^{\text{th}} \text{ price is selected to be} \\ & \text{shipped until } k^{\text{th}} \text{ delivery time} \\ 0 & \text{otherwise} \end{cases}$$

## MODEL III

### Objective Function

$$\max \sum_{i=1}^N \sum_{j=0}^{|J_i|} \sum_{k=0}^K x_{ijk} (w_{ij} - c_i) Q_{ij} - \sum_{i=1}^N \sum_{j=0}^{|J_i|} \sum_{k=0}^K \frac{x_{ijk} p_i h_i Q_{ij} (Q_{ij} + 1)}{2} \quad (29)$$

### Constraints

If order accepted, determine a single price and delivery time

$$\sum_{j=0}^{|J_i|} \sum_{k=0}^K x_{ijk} \leq 1 \quad \text{for all } i \quad (30)$$

Do not exceed the capacity

$$\sum_{i=1}^N \sum_{j=0}^{|J_i|} x_{ijk} p_i Q_{ij} \leq TC_k \quad \text{for all } k \quad (31)$$

Define range of variables

$$x_{ijk} \in \{0,1\} \quad \text{for all } (i, j, k) \quad (32)$$

The objective function in the above model includes the manufacturer's revenue from sales, and inventory holding costs for all orders that are accepted. Expression (30) ensures that if an order is accepted, a single *wholesale price, delivery date* pair is chosen for this order. Expression (31) guarantees that the total

capacity until each due-date is not exceeded. Finally, Expression (32) defines binary variables.

# Chapter 5

## EXPERIMENTAL DESIGN AND NUMERICAL RESULTS

In this section, we numerically compare Contract DTDP with Contract FWTP. We consider homogeneous retailers in the sense that their ordering system and its parameters, introduced and defined as in the previous chapter, are identical. In the experiments, we characterize different market settings and determine which contract type provides better performance under which scenarios. The numerical results are interpreted as managerial insights, which should provide useful guidance for pricing and production-scheduling decisions in various supply chain settings.

### 5.1 Experimental Design

We consider six homogeneous retailers. Each retailer gives an order and all orders are for a single product. Retailer  $i$  has a Normal demand with a mean of  $\mu_i$  and a standard deviation of  $\sigma_i$ , for  $i = 1, 2, \dots, 6$ . The length of the *demand period* is set  $t_4 - t_2 = 2000$  (see Figure-1). We use Normal demand in order to make the numerical analysis simple. More specifically, we exploit the fact that the sum of Normal random variables is Normal. Unit retailer price and wholesale price of the product in the market are  $r_i = 1$  and  $\bar{w}_i = 0.75$ , respectively. Retailers are not

subject to any salvage and backlog costs (i.e.  $b_i = 0$ ,  $g_i = 0$ ,  $i = 1, \dots, 6$ ). The *production period* is set half as long as the *demand period* (i.e.  $t_3 - t_1 = 1000$ ).

Recall that Contract *DTDP* requires the number of due dates to be set as an endogenous variable, Preliminary experimentation indicates that this variable may have a considerable effect on the profit obtained by the manufacturer under Contract *DTDP*. Note that no such effect is present for Contract *FWTP* as it contains a single due date which is the beginning of the *demand period*. In the case of Contract *DTDP*, on the other hand, it is crucially important to set the number of due dates in accordance with the total production capacity in the *demand period*. This is mainly due to the fact that the manufacturer applies discounted wholesale prices for the orders whose due dates are in the *demand period* and there will be loss in profits for the manufacturer if there are time gaps between due dates and production completion times. In other words, if the manufacturer ships the orders exactly at their due dates, then discounts will be less and hence, the profits of the manufacturer will be larger. As a result, the profitability of the manufacturer increases with the number of due dates under Contract *DTDP*.

Some preliminary experimentation indicates that the number of available due dates to ensure better performance of Contract *DTDP* increases with the order size and the number of orders to be shipped within the *demand period*. In our experimental setting, the largest order size is 97 and we can ship at most six orders within the *demand period*. Consequently, we use 582 capacity units (set as six times the size of the largest order) to graphically illustrate this effect in Figure 2 (Data is given in Appendix-C). The figure indicates that profitability shows some improvement as the number of due dates increases up to a certain point and stabilizes thereafter. Based on preliminary results under different settings, we fix the number of due dates at 80 in the remainder of our experimentation.

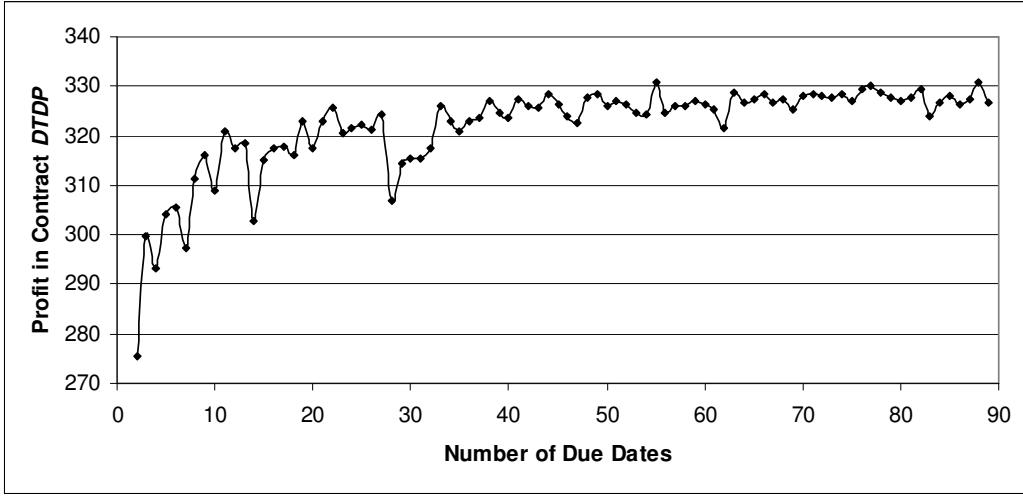


Figure-2: Profitability of Contract *DTDP* as a function of the number of due dates

We vary several factors and compare the performance of the two contract types. On the retailer side, the only factor that we manipulate is the stochasticity of demand. On the manufacturer side, we focus on production capacity before and after the beginning of the *demand period*, as well as the production, inventory and tardiness costs.

*Stochasticity* is measured by the coefficient of variation defined as  $CV_i = \sigma_i / \mu_i$  for retailer  $i$ .  $CV_i$  directly affects the optimal order sizes, which are given by  $Q_i^* = \mu_i \left( CV_i \times (F_i^k)^{-1} (1 - \bar{w}_i) + 1 \right)$ . In Contract *DTDP*, optimal order sizes to be shipped within the *demand period* are affected by two issues: (1) loss of the demand between the due date and time of order fulfillment (2) discounts offered by the manufacturer. In the equation above, an optimal order size is determined as the sum of two terms. Stochasticity only affects the first one of these terms and it is independent of the aforementioned two issues affecting the optimal order size. This allows us to analyze the effect of stochasticity while fixing all decisions.

Our focus is to numerically analyze our proposal in different levels of stochasticity and in the experimentation, we use two levels for  $CV_i$  which are 0.05 and 0.3 and a fixed mean value of  $\mu_i = 100$ .

Assuming that the production capacity is uniform throughout the production period, it is helpful to consider the production period as of two parts before and after the beginning of the *demand period*. These two parts are of length  $(t_2 - t_1)$  and  $(t_3 - t_2)$ , respectively. We vary the capacity prior to the beginning of the *demand period* by varying  $t_2 - t_1$  between 1 to 585 units. This factor is important in that if  $(t_2 - t_1)$  is long enough to produce all orders, then the two contract types will perform equally well in terms of the manufacturer's profit. Thus, we would like to illustrate the effect of capacity in  $(t_2 - t_1)$  by considering various levels of this factor. For  $t_3 - t_2$  or capacity during the *demand period*, we use four levels, selected as 140, 280, 420 and 585.

*Production and inventory costs* are two important factors affecting manufacturer's production decisions and the relative performance of the two contract types. We consider the following five levels for the production cost: 0, 0.1, 0.2, 0.3 and 0.4. Similarly, we use five levels also for the inventory cost, which are set at 0, 0.002, 0.003, 0.004 and 0.005. For any given production and inventory cost combination, we select appropriate market and wholesale prices so that the resulting manufacturer's profit is positive. The values used for this factor is determined in a way that the manufacturer has some positive profit. Otherwise, the manufacturer would not prefer to process any order.

*Tardiness cost* is only included in contract FWTP. It affects the total profits and the number of orders accepted to be processed in contract FWTP. For instance, if it is high enough, there will be no order committed to be shipped during the *demand period*. We use the values of 0.0001, 0.0002, 0.0003, 0.0004

and 0.0005 as five alternative levels of this factor. To assess the feasibility of this choice, we focus on the highest possible tardiness penalty, which occurs when the selected order is shipped at the end of the *production period*. Similar to the previous factor, the manufacturer has incentive to make production under these levels for this factor. Thus, our numbers are feasible under this setting.. The tardiness values can also be interpreted as a measure of the relative strength of the two parties in the trade. If the tardiness cost is high, retailers are more influential. Otherwise, the manufacturer has virtually no competition and hence can govern the terms.

## 5.2 Numerical Results

In this section, we present the experimental results in terms of the percentage difference of the performance of Contract *DTDP* over that of Contract *FWTP*. We consider one factor at a time and use average percentage difference in the graphs. The performance measure is mathematically defined by the following expression.

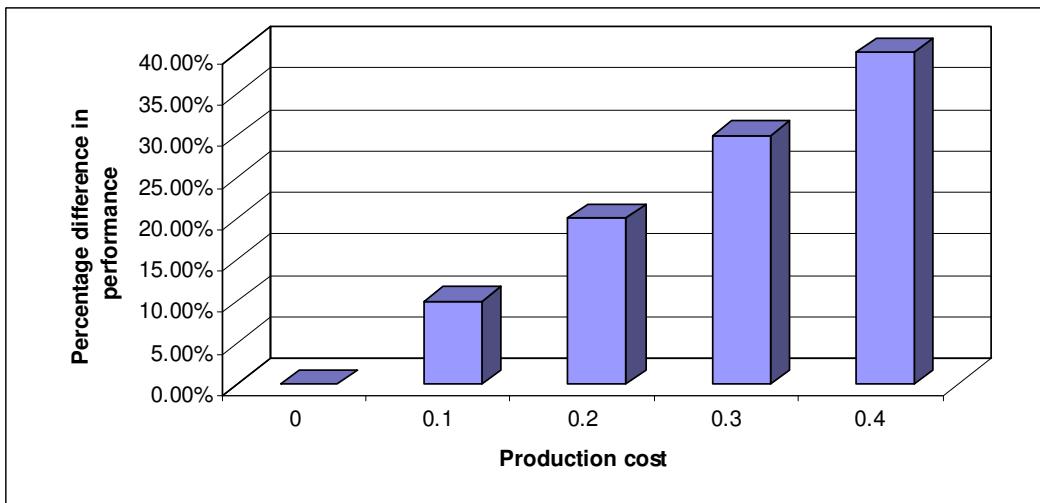
$$100 \times \sum_{i=1}^6 (\Psi_i^{DTDP}(Q, w, C) - \Psi_i^{FWTP}(Q, w, C)) \Big/ \sum_{i=1}^6 \Psi_i^{FWTP}(Q, w, C)$$

The raw data to illustrate the comparison between the two contracts is also given in Appendix-A. In addition, the summary of average performance for each factor is included in Appendix-B.

In what follows, we first discuss the effects of production, inventory and tardiness costs. Then we proceed with analyses of the effect imposed by the portion of the production period residing within the demand period. We conclude our experimental investigation with observations on the impact of the degree of stochasticity of retailer demand on the relative performance of the two contracts.

**The Effect of Production Cost:** Figure-3 depicts the average percentage performance of Contract *DTDP* over contract *FWTP* for five different values of production cost. The results indicate that Contract *DTDP* becomes more

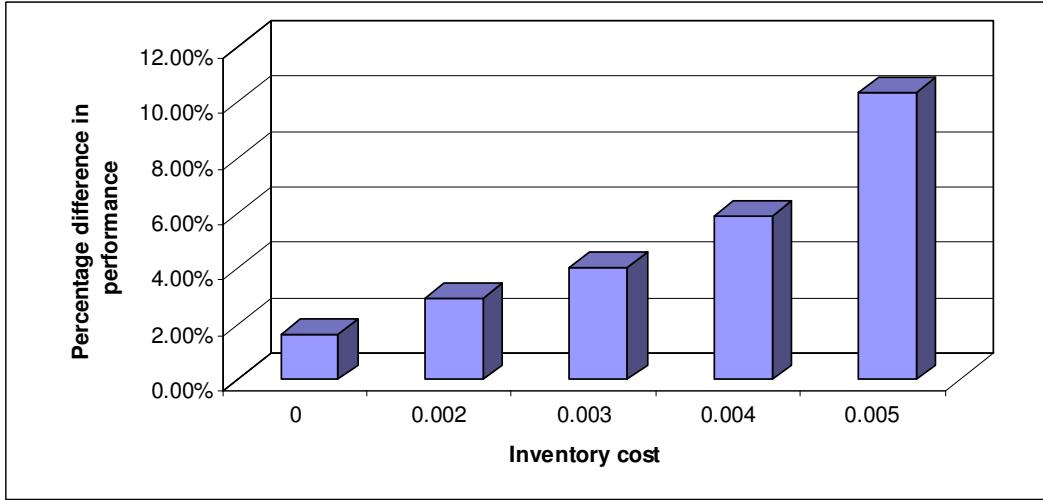
preferable as the production cost increases in the market. More specifically, if the cost is 0.4, then the relative performance is around 38%, which means that Contract *DTDP* generates 38% more profit relative to Contract *FWTP*. Interestingly, Contract *DTDP* is still more preferable even if there is no production cost at all. This observation may be important also in that it once again emphasizes the value of information sharing in supply chain settings.



**Figure-3:** The effect of production cost on the performance of *DTDP* relative to that of *FWTP*

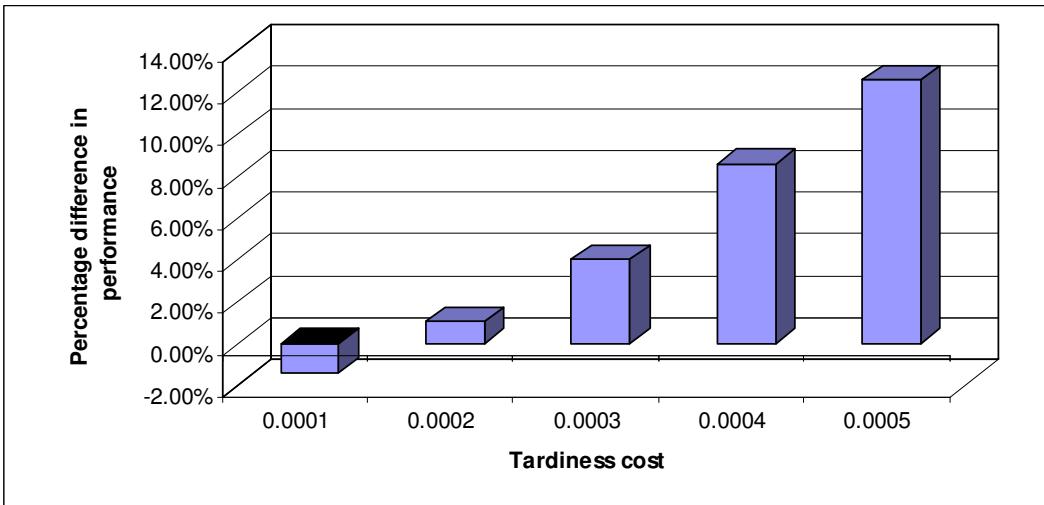
**The Effect of Inventory Cost:** Figure-4 illustrates the effect of inventory cost on the relative performance of *DTDP*. In parallel with the effect of the production cost, Contract *DTDP* generates more profit than Contract *FWTP* and this difference becomes more marked for increasing values of the inventory cost. This observation can be explained based on the formulation of the two contracts. In both contracts, inventory cost per order is proportional to the square of the order size. We know that order sizes in Contract *DTDP* decreases if the order is committed to be shipped within the *demand period*. This is simply because it

considers the loss in demand for deliveries within that period. Thus, Contract *DTDP* reduces inventory costs, generates more profits and becomes more and more desirable in the market with increasing inventory costs.



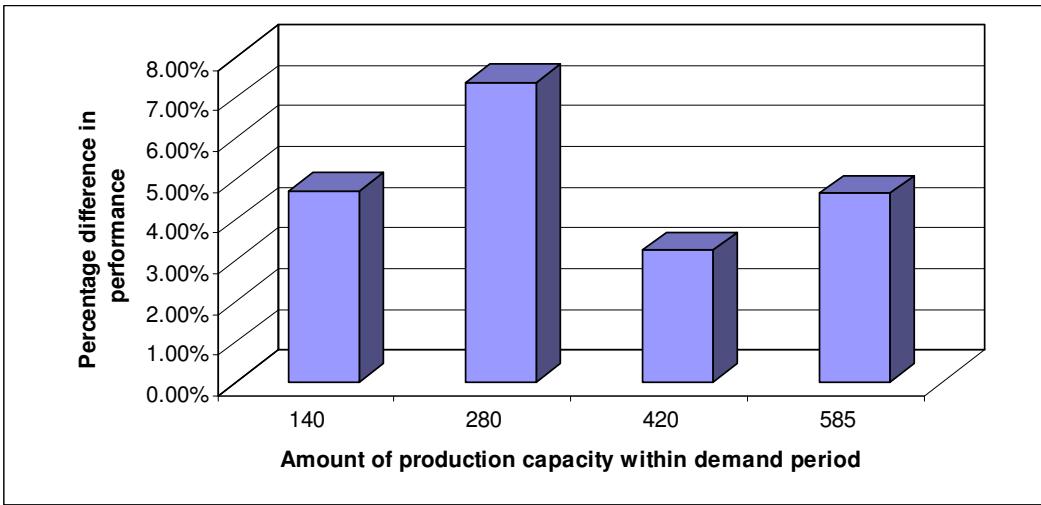
**Figure-4:** The effect of inventory cost on the performance of *DTDP* relative to that of *FWTP*

**The Effect of Tardiness Cost:** The impact of tardiness cost on the relative performance of the two contracts is shown in Figure-5. Recall that tardiness cost has no effect on the manufacturer's profit under Contract *DTDP*. Although Contract *FWTP* outperforms Contract *DTDP* in some instances with lower tardiness cost. However, using Contract *DTDP* is more advantageous on the average. As it is expected, the difference in performance becomes increasingly more significant as the tardiness cost increases and it changes as an approximate linear function of the tardiness cost.



**Figure-5:** The effect of tardiness cost on the performance of DTDP relative to that of FWTP

**The Effect of Production Capacity within *Demand Period*:** Figure-6 provides a graphical summary of the effect of production capacity within the *demand period* on the relative performance measure. Contract *DTDP* outperforms FWTP on average. Furthermore, there is an indication that the manufacturer should carefully decide on the optimal capacity allocation within the demand period to ensure maximum profitability. This is reasonable because there will be some optimal production capacity allocations within the *demand period*.



**Figure-6:** The effect of production capacity within *demand period* on the performance of DTDP relative to that of FWTP

**The Effect of Stochasticity:** The effect of demand stochasticity on the average percentage difference in performance is depicted in Figure-7. Contract *DTDP* generates more profits in both levels of the factor on average. Difference in performance is more significant when the CV is set at 5%. This observation is due to the fact that retailers tend to place smaller orders in a highly stochastic demand environment, and hence the manufacturer is able to complete the production in shorter time. This implies that the manufacturer incurs less tardiness cost in Contract *FWTP* under a highly stochastic demand and the difference in the performance of the two contracts decreases as the demand stochasticity gets higher.

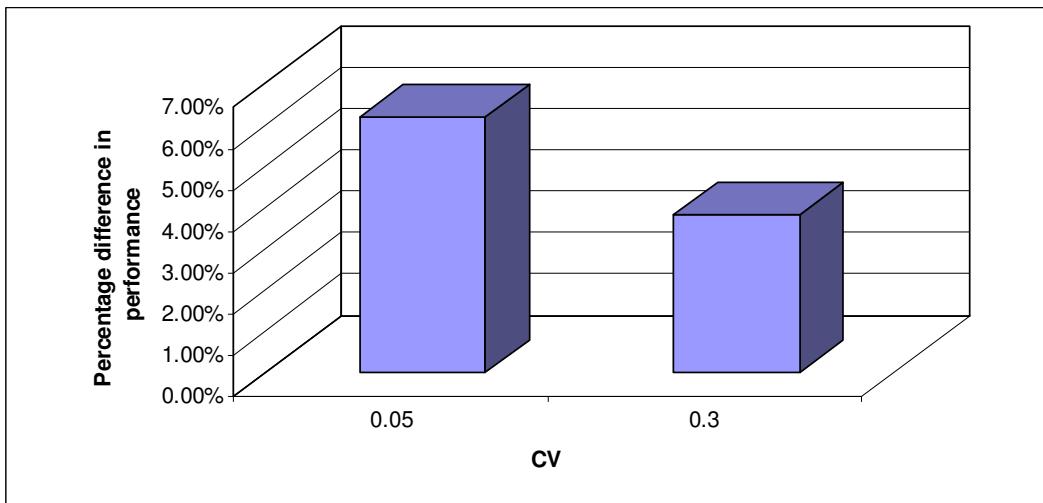


Figure-7: The effect of stochasticity on the performance of DTDP relative to that of FWTP

# Chapter 6

## CONCLUSION

This thesis considered the problem of coordinating the pricing and production scheduling decisions of a manufacturer who sells a single product to multiple retailers in a two-stage decentralized supply chain operating under a single period stochastic demand environment. Retailers' demand information is assumed to be known by the manufacturer. The main approach is to prepare price menus to set different wholesale prices for different due dates and have the retailers adjust their optimal order quantities and delivery times in a way to support a more efficient utilization of manufacturer's available production capacity.

Application of the solution approach utilizes two separate procedures. The first procedure handles the preparation of the price menu composed of wholesale price and due-date pairs. This menu is prepared such that the buyers can attain at least the profit levels yielded by the base scenario with a fixed wholesale price and tardiness costs. There exists an optimal order quantity corresponding to each one of the pairs in the menu. The second procedure uses the information implied by the price menu generated by the first routine and solves the manufacturer's optimization problem to maximize his/her overall profits while respecting the capacity and delivery time constraints. A mathematical optimization program is proposed to solve this NP-hard deterministic problem. The solution reveals which orders are to be accepted at which prices, due-dates and order quantities.

Proposed methodology is tested via computational experimentation, and some basic managerial insights are produced based on the experimental results. The underlying notion supporting the proposed approach is that in supply chain systems, a manufacturer who has access to the demand information of its customers has the ability to form its price menus as a function of both time and quantity so as to maximize its profit without making the profit levels of its customers any worse.

The performance of the proposed approach in terms of the manufacturer's profit level is tested against that of the base scenario through computational experimentation. The scenarios considered in the experimentation are generated systematically by varying certain factors such as the level of stochasticity in retailers' demand distribution, the magnitudes of the production, inventory holding and tardiness costs, and the portions of the production period lying before and after the beginning of the demand season. Results briefly indicate that the proposed approach has significant advantages over the base scenario particularly when the retailers experience high demands with low levels of stochasticity, and the manufacturer has high production, inventory holding and tardiness costs.

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# APPENDIX

## A. The Raw Data Containing All Instances in Experimental Design

There are four tables and each of them is for one level of production capacity within the *demand period*. The first four columns contain the levels of stochasticity, production, tardiness and inventory costs. The last column is the percentage difference of the performance of Contract *DTDP* over that of Contract *FWTP*.

**Table 1a: Raw Data for Production Capacity of 140 within the *demand period***

Production capacity within demand period = 140				
CV	Production cost	Inventory cost	Tardiness cost	Performance
5	0	0	0	3.37%
5	0.1	0	0	3.10%
5	0.2	0	0	2.73%
5	0.3	0	0	2.18%
5	0.4	0	0	1.31%
5	0	0.002	0	3.46%
5	0.1	0.002	0	3.16%
5	0.2	0.002	0	2.72%
5	0.3	0.002	0	2.01%
5	0.4	0.002	0	0.80%
5	0	0.003	0	3.52%
5	0.1	0.003	0	3.20%
5	0.2	0.003	0	2.72%
5	0.3	0.003	0	1.97%
5	0.4	0.003	0	0.41%
5	0	0.004	0	3.59%
5	0.1	0.004	0	3.25%
5	0.2	0.004	0	2.78%
5	0.3	0.004	0	1.92%
5	0.4	0.004	0	-0.17%
5	0	0.005	0	3.68%
5	0.1	0.005	0	3.37%

5	0.2	0.005	0	2.88%
5	0.3	0.005	0	1.90%
5	0.4	0.005	0	-1.19%
5	0	0	0.0001	3.80%
5	0.1	0	0.0001	3.60%
5	0.2	0	0.0001	3.33%
5	0.3	0	0.0001	2.92%
5	0.4	0	0.0001	2.26%
5	0	0.002	0.0001	3.97%
5	0.1	0.002	0.0001	3.76%
5	0.2	0.002	0.0001	3.46%
5	0.3	0.002	0.0001	2.98%
5	0.4	0.002	0.0001	2.17%
5	0	0.003	0.0001	4.07%
5	0.1	0.003	0.0001	3.87%
5	0.2	0.003	0.0001	3.55%
5	0.3	0.003	0.0001	3.10%
5	0.4	0.003	0.0001	2.16%
5	0	0.004	0.0001	4.19%
5	0.1	0.004	0.0001	3.99%
5	0.2	0.004	0.0001	3.75%
5	0.3	0.004	0.0001	3.30%
5	0.4	0.004	0.0001	2.25%
5	0	0.005	0.0001	4.34%
5	0.1	0.005	0.0001	4.21%
5	0.2	0.005	0.0001	4.02%
5	0.3	0.005	0.0001	3.66%
5	0.4	0.005	0.0001	2.74%
5	0	0	0.0002	4.25%
5	0.1	0	0.0002	4.12%
5	0.2	0	0.0002	3.94%
5	0.3	0	0.0002	3.68%
5	0.4	0	0.0002	3.25%
5	0	0.002	0.0002	4.48%
5	0.1	0.002	0.0002	4.37%
5	0.2	0.002	0.0002	4.22%
5	0.3	0.002	0.0002	3.96%
5	0.4	0.002	0.0002	3.60%
5	0	0.003	0.0002	4.63%
5	0.1	0.003	0.0002	4.54%
5	0.2	0.003	0.0002	4.41%

5	0.3	0.003	0.0002	4.28%
5	0.4	0.003	0.0002	4.01%
5	0	0.004	0.0002	4.81%
5	0.1	0.004	0.0002	4.75%
5	0.2	0.004	0.0002	4.74%
5	0.3	0.004	0.0002	4.74%
5	0.4	0.004	0.0002	4.86%
5	0	0.005	0.0002	5.02%
5	0.1	0.005	0.0002	5.07%
5	0.2	0.005	0.0002	5.19%
5	0.3	0.005	0.0002	5.52%
5	0.4	0.005	0.0002	7.20%
5	0	0	0.0004	5.15%
5	0.1	0	0.0004	5.17%
5	0.2	0	0.0004	5.20%
5	0.3	0	0.0004	5.24%
5	0.4	0	0.0004	5.31%
5	0	0.002	0.0004	5.53%
5	0.1	0.002	0.0004	5.63%
5	0.2	0.002	0.0004	5.78%
5	0.3	0.002	0.0004	6.03%
5	0.4	0.002	0.0004	6.66%
5	0	0.003	0.0004	5.78%
5	0.1	0.003	0.0004	5.94%
5	0.2	0.003	0.0004	6.19%
5	0.3	0.003	0.0004	6.74%
5	0.4	0.003	0.0004	8.04%
5	0	0.004	0.0004	6.06%
5	0.1	0.004	0.0004	6.32%
5	0.2	0.004	0.0004	6.81%
5	0.3	0.004	0.0004	7.80%
5	0.4	0.004	0.0004	10.77%
5	0	0.005	0.0004	6.42%
5	0.1	0.005	0.0004	6.86%
5	0.2	0.005	0.0004	7.67%
5	0.3	0.005	0.0004	9.57%
5	0.4	0.005	0.0004	18.44%
5	0	0	0.0005	5.61%
5	0.1	0	0.0005	5.71%
5	0.2	0	0.0005	5.84%
5	0.3	0	0.0005	6.05%

5	0.4	0	0.0005	6.39%
5	0	0.002	0.0005	6.07%
5	0.1	0.002	0.0005	6.28%
5	0.2	0.002	0.0005	6.59%
5	0.3	0.002	0.0005	7.11%
5	0.4	0.002	0.0005	8.29%
5	0	0.003	0.0005	6.36%
5	0.1	0.003	0.0005	6.66%
5	0.2	0.003	0.0005	7.12%
5	0.3	0.003	0.0005	8.05%
5	0.4	0.003	0.0005	10.24%
5	0	0.004	0.0005	6.71%
5	0.1	0.004	0.0005	7.13%
5	0.2	0.004	0.0005	7.89%
5	0.3	0.004	0.0005	9.44%
5	0.4	0.004	0.0005	14.17%
5	0	0.005	0.0005	7.13%
5	0.1	0.005	0.0005	7.79%
5	0.2	0.005	0.0005	8.98%
5	0.3	0.005	0.0005	11.79%
5	0.4	0.005	0.0005	25.92%
30	0	0	0	2.69%
30	0	0.002	0	2.74%
30	0	0.003	0	2.77%
30	0	0.004	0	2.82%
30	0	0.005	0	2.87%
30	0.1	0	0	2.55%
30	0.1	0.002	0	2.60%
30	0.1	0.003	0	2.63%
30	0.1	0.004	0	2.67%
30	0.1	0.005	0	2.73%
30	0.2	0	0	2.36%
30	0.2	0.002	0	2.40%
30	0.2	0.003	0	2.43%
30	0.2	0.004	0	2.47%
30	0.2	0.005	0	2.53%
30	0.3	0	0	2.10%
30	0.3	0.002	0	2.10%
30	0.3	0.003	0	2.11%
30	0.3	0.004	0	2.13%
30	0.3	0.005	0	2.16%

30	0.4	0	0	1.69%
30	0.4	0.002	0	1.59%
30	0.4	0.003	0	1.53%
30	0.4	0.004	0	1.44%
30	0.4	0.005	0	1.33%
30	0	0	0.0001	3.06%
30	0	0.002	0.0001	3.16%
30	0	0.003	0.0001	3.22%
30	0	0.004	0.0001	3.30%
30	0	0.005	0.0001	3.39%
30	0.1	0	0.0001	2.98%
30	0.1	0.002	0.0001	3.09%
30	0.1	0.003	0.0001	3.17%
30	0.1	0.004	0.0001	3.26%
30	0.1	0.005	0.0001	3.37%
30	0.2	0	0.0001	2.87%
30	0.2	0.002	0.0001	3.00%
30	0.2	0.003	0.0001	3.09%
30	0.2	0.004	0.0001	3.20%
30	0.2	0.005	0.0001	3.35%
30	0.3	0	0.0001	2.72%
30	0.3	0.002	0.0001	2.87%
30	0.3	0.003	0.0001	2.97%
30	0.3	0.004	0.0001	3.12%
30	0.3	0.005	0.0001	3.32%
30	0.4	0	0.0001	2.50%
30	0.4	0.002	0.0001	2.64%
30	0.4	0.003	0.0001	2.77%
30	0.4	0.004	0.0001	2.96%
30	0.4	0.005	0.0001	3.29%
30	0	0	0.0002	3.45%
30	0	0.002	0.0002	3.59%
30	0	0.003	0.0002	3.68%
30	0	0.004	0.0002	3.79%
30	0	0.005	0.0002	3.92%
30	0.1	0	0.0002	3.42%
30	0.1	0.002	0.0002	3.60%
30	0.1	0.003	0.0002	3.71%
30	0.1	0.004	0.0002	3.85%
30	0.1	0.005	0.0002	4.02%
30	0.2	0	0.0002	3.40%

30	0.2	0.002	0.0002	3.62%
30	0.2	0.003	0.0002	3.77%
30	0.2	0.004	0.0002	3.95%
30	0.2	0.005	0.0002	4.19%
30	0.3	0	0.0002	3.36%
30	0.3	0.002	0.0002	3.65%
30	0.3	0.003	0.0002	3.86%
30	0.3	0.004	0.0002	4.14%
30	0.3	0.005	0.0002	4.52%
30	0.4	0	0.0002	3.32%
30	0.4	0.002	0.0002	3.73%
30	0.4	0.003	0.0002	4.07%
30	0.4	0.004	0.0002	4.57%
30	0.4	0.005	0.0002	5.38%
30	0	0	0.0004	4.22%
30	0	0.002	0.0004	4.47%
30	0	0.003	0.0004	4.62%
30	0	0.004	0.0004	4.80%
30	0	0.005	0.0004	5.00%
30	0.1	0	0.0004	4.33%
30	0.1	0.002	0.0004	4.64%
30	0.1	0.003	0.0004	4.84%
30	0.1	0.004	0.0004	5.08%
30	0.1	0.005	0.0004	5.36%
30	0.2	0	0.0004	4.47%
30	0.2	0.002	0.0004	4.89%
30	0.2	0.003	0.0004	5.17%
30	0.2	0.004	0.0004	5.52%
30	0.2	0.005	0.0004	5.95%
30	0.3	0	0.0004	4.69%
30	0.3	0.002	0.0004	5.30%
30	0.3	0.003	0.0004	5.73%
30	0.3	0.004	0.0004	6.30%
30	0.3	0.005	0.0004	7.09%
30	0.4	0	0.0004	5.05%
30	0.4	0.002	0.0004	6.04%
30	0.4	0.003	0.0004	6.85%
30	0.4	0.004	0.0004	8.06%
30	0.4	0.005	0.0004	10.08%
30	0	0	0.0005	4.62%
30	0	0.002	0.0005	4.92%

30	0	0.003	0.0005	5.10%
30	0	0.004	0.0005	5.31%
30	0	0.005	0.0005	5.56%
30	0.1	0	0.0005	4.79%
30	0.1	0.002	0.0005	5.17%
30	0.1	0.003	0.0005	5.42%
30	0.1	0.004	0.0005	5.71%
30	0.1	0.005	0.0005	6.06%
30	0.2	0	0.0005	5.02%
30	0.2	0.002	0.0005	5.55%
30	0.2	0.003	0.0005	5.90%
30	0.2	0.004	0.0005	6.33%
30	0.2	0.005	0.0005	6.88%
30	0.3	0	0.0005	5.37%
30	0.3	0.002	0.0005	6.15%
30	0.3	0.003	0.0005	6.71%
30	0.3	0.004	0.0005	7.44%
30	0.3	0.005	0.0005	8.46%
30	0.4	0	0.0005	5.96%
30	0.4	0.002	0.0005	7.27%
30	0.4	0.003	0.0005	8.35%
30	0.4	0.004	0.0005	9.98%
30	0.4	0.005	0.0005	12.75%

**Table 1b: Raw Data for Production Capacity of 280 within the *demand period***

Production capacity within demand period = 280				
CV	Production cost	Inventory cost	Tardiness cost	Performance
5	0	0	0.0001	1.93%
5	0	0.002	0.0001	2.39%
5	0	0.003	0.0001	2.72%
5	0	0.004	0.0001	3.12%
5	0	0.005	0.0001	3.60%
5	0.1	0	0.0001	1.62%
5	0.1	0.002	0.0001	2.16%
5	0.1	0.003	0.0001	2.54%
5	0.1	0.004	0.0001	3.01%
5	0.1	0.005	0.0001	3.61%
5	0.2	0	0.0001	1.20%
5	0.2	0.002	0.0001	1.83%
5	0.2	0.003	0.0001	2.26%
5	0.2	0.004	0.0001	2.84%
5	0.2	0.005	0.0001	3.62%
5	0.3	0	0.0001	0.63%
5	0.3	0.002	0.0001	1.28%
5	0.3	0.003	0.0001	1.79%
5	0.3	0.004	0.0001	2.51%
5	0.3	0.005	0.0001	3.68%
5	0.4	0	0.0001	-0.27%
5	0.4	0.002	0.0001	0.28%
5	0.4	0.003	0.0001	0.80%
5	0.4	0.004	0.0001	1.78%
5	0.4	0.005	0.0001	4.24%
5	0	0	0.0002	2.97%
5	0	0.002	0.0002	3.62%
5	0	0.003	0.0002	4.06%
5	0	0.004	0.0002	4.60%
5	0	0.005	0.0002	5.24%
5	0.1	0	0.0002	2.83%
5	0.1	0.002	0.0002	3.62%
5	0.1	0.003	0.0002	4.17%
5	0.1	0.004	0.0002	4.85%
5	0.1	0.005	0.0002	5.71%
5	0.2	0	0.0002	2.65%
5	0.2	0.002	0.0002	3.64%
5	0.2	0.003	0.0002	4.34%

5	0.2	0.004	0.0002	5.26%
5	0.2	0.005	0.0002	6.53%
5	0.3	0	0.0002	2.42%
5	0.3	0.002	0.0002	3.66%
5	0.3	0.003	0.0002	4.64%
5	0.3	0.004	0.0002	6.08%
5	0.3	0.005	0.0002	8.41%
5	0.4	0	0.0002	2.08%
5	0.4	0.002	0.0002	3.77%
5	0.4	0.003	0.0002	5.41%
5	0.4	0.004	0.0002	8.57%
5	0.4	0.005	0.0002	17.15%
5	0	0	0.0003	4.05%
5	0	0.002	0.0003	4.88%
5	0	0.003	0.0003	5.45%
5	0	0.004	0.0003	6.13%
5	0	0.005	0.0003	6.96%
5	0.1	0	0.0003	4.09%
5	0.1	0.002	0.0003	5.14%
5	0.1	0.003	0.0003	5.87%
5	0.1	0.004	0.0003	6.77%
5	0.1	0.005	0.0003	7.93%
5	0.2	0	0.0003	4.15%
5	0.2	0.002	0.0003	5.54%
5	0.2	0.003	0.0003	6.53%
5	0.2	0.004	0.0003	7.85%
5	0.2	0.005	0.0003	9.68%
5	0.3	0	0.0003	4.31%
5	0.3	0.002	0.0003	6.22%
5	0.3	0.003	0.0003	7.74%
5	0.3	0.004	0.0003	10.02%
5	0.3	0.005	0.0003	13.82%
5	0.4	0	0.0003	4.59%
5	0.4	0.002	0.0003	7.63%
5	0.4	0.003	0.0003	10.68%
5	0.4	0.004	0.0003	16.88%
5	0.4	0.005	0.0003	36.59%
5	0	0	0.0004	5.16%
5	0	0.002	0.0004	6.19%
5	0	0.003	0.0004	6.89%
5	0	0.004	0.0004	7.73%

5	0	0.005	0.0004	8.76%
5	0.1	0	0.0004	5.39%
5	0.1	0.002	0.0004	6.73%
5	0.1	0.003	0.0004	7.65%
5	0.1	0.004	0.0004	8.80%
5	0.1	0.005	0.0004	10.29%
5	0.2	0	0.0004	5.72%
5	0.2	0.002	0.0004	7.55%
5	0.2	0.003	0.0004	8.86%
5	0.2	0.004	0.0004	10.62%
5	0.2	0.005	0.0004	13.11%
5	0.3	0	0.0004	6.29%
5	0.3	0.002	0.0004	8.95%
5	0.3	0.003	0.0004	11.12%
5	0.3	0.004	0.0004	14.42%
5	0.3	0.005	0.0004	20.11%
5	0.4	0	0.0004	7.29%
5	0.4	0.002	0.0004	11.94%
5	0.4	0.003	0.0004	16.81%
5	0.4	0.004	0.0004	27.48%
5	0.4	0.005	0.0004	58.24%
5	0	0	0.0005	6.30%
5	0	0.002	0.0005	7.55%
5	0	0.003	0.0005	8.39%
5	0	0.004	0.0005	9.40%
5	0	0.005	0.0005	10.64%
5	0.1	0	0.0005	6.74%
5	0.1	0.002	0.0005	8.39%
5	0.1	0.003	0.0005	9.52%
5	0.1	0.004	0.0005	10.95%
5	0.1	0.005	0.0005	12.80%
5	0.2	0	0.0005	7.37%
5	0.2	0.002	0.0005	9.67%
5	0.2	0.003	0.0005	11.35%
5	0.2	0.004	0.0005	13.62%
5	0.2	0.005	0.0005	16.87%
5	0.3	0	0.0005	8.39%
5	0.3	0.002	0.0005	11.91%
5	0.3	0.003	0.0005	14.82%
5	0.3	0.004	0.0005	19.37%
5	0.3	0.005	0.0005	27.56%

5	0.4	0	0.0005	10.20%
5	0.4	0.002	0.0005	16.80%
5	0.4	0.003	0.0005	24.10%
5	0.4	0.004	0.0005	41.31%
5	0.4	0.005	0.0005	79.83%
30	0	0	0.0001	1.76%
30	0	0.002	0.0001	2.02%
30	0	0.003	0.0001	2.17%
30	0	0.004	0.0001	2.36%
30	0	0.005	0.0001	2.57%
30	0.1	0	0.0001	1.63%
30	0.1	0.002	0.0001	1.92%
30	0.1	0.003	0.0001	2.10%
30	0.1	0.004	0.0001	2.32%
30	0.1	0.005	0.0001	2.59%
30	0.2	0	0.0001	1.45%
30	0.2	0.002	0.0001	1.78%
30	0.2	0.003	0.0001	2.00%
30	0.2	0.004	0.0001	2.27%
30	0.2	0.005	0.0001	2.62%
30	0.3	0	0.0001	1.19%
30	0.3	0.002	0.0001	1.57%
30	0.3	0.003	0.0001	1.85%
30	0.3	0.004	0.0001	2.21%
30	0.3	0.005	0.0001	2.71%
30	0.4	0	0.0001	0.80%
30	0.4	0.002	0.0001	1.22%
30	0.4	0.003	0.0001	1.57%
30	0.4	0.004	0.0001	2.09%
30	0.4	0.005	0.0001	2.94%
30	0	0	0.0002	2.60%
30	0	0.002	0.0002	2.97%
30	0	0.003	0.0002	3.19%
30	0	0.004	0.0002	3.45%
30	0	0.005	0.0002	3.75%
30	0.1	0	0.0002	2.60%
30	0.1	0.002	0.0002	3.04%
30	0.1	0.003	0.0002	3.32%
30	0.1	0.004	0.0002	3.64%
30	0.1	0.005	0.0002	4.05%
30	0.2	0	0.0002	2.60%

30	0.2	0.002	0.0002	3.15%
30	0.2	0.003	0.0002	3.51%
30	0.2	0.004	0.0002	3.96%
30	0.2	0.005	0.0002	4.53%
30	0.3	0	0.0002	2.61%
30	0.3	0.002	0.0002	3.33%
30	0.3	0.003	0.0002	3.85%
30	0.3	0.004	0.0002	4.53%
30	0.3	0.005	0.0002	5.48%
30	0.4	0	0.0002	2.63%
30	0.4	0.002	0.0002	3.68%
30	0.4	0.003	0.0002	4.54%
30	0.4	0.004	0.0002	5.83%
30	0.4	0.005	0.0002	7.97%
30	0	0	0.0003	3.47%
30	0	0.002	0.0003	3.95%
30	0	0.003	0.0003	4.24%
30	0	0.004	0.0003	4.58%
30	0	0.005	0.0003	4.98%
30	0.1	0	0.0003	3.61%
30	0.1	0.002	0.0003	4.20%
30	0.1	0.003	0.0003	4.58%
30	0.1	0.004	0.0003	5.03%
30	0.1	0.005	0.0003	5.58%
30	0.2	0	0.0003	3.80%
30	0.2	0.002	0.0003	4.59%
30	0.2	0.003	0.0003	5.11%
30	0.2	0.004	0.0003	5.75%
30	0.2	0.005	0.0003	6.57%
30	0.3	0	0.0003	4.10%
30	0.3	0.002	0.0003	5.21%
30	0.3	0.003	0.0003	6.00%
30	0.3	0.004	0.0003	7.05%
30	0.3	0.005	0.0003	8.52%
30	0.4	0	0.0003	4.59%
30	0.4	0.002	0.0003	6.37%
30	0.4	0.003	0.0003	7.83%
30	0.4	0.004	0.0003	10.08%
30	0.4	0.005	0.0003	13.97%
30	0	0	0.0004	4.36%
30	0	0.002	0.0004	4.96%

30	0	0.003	0.0004	5.33%
30	0	0.004	0.0004	5.76%
30	0	0.005	0.0004	6.26%
30	0.1	0	0.0004	4.65%
30	0.1	0.002	0.0004	5.42%
30	0.1	0.003	0.0004	5.91%
30	0.1	0.004	0.0004	6.49%
30	0.1	0.005	0.0004	7.20%
30	0.2	0	0.0004	5.05%
30	0.2	0.002	0.0004	6.09%
30	0.2	0.003	0.0004	6.79%
30	0.2	0.004	0.0004	7.66%
30	0.2	0.005	0.0004	8.76%
30	0.3	0	0.0004	5.67%
30	0.3	0.002	0.0004	7.20%
30	0.3	0.003	0.0004	8.31%
30	0.3	0.004	0.0004	9.79%
30	0.3	0.005	0.0004	11.90%
30	0.4	0	0.0004	6.69%
30	0.4	0.002	0.0004	9.31%
30	0.4	0.003	0.0004	11.51%
30	0.4	0.004	0.0004	15.00%
30	0.4	0.005	0.0004	21.31%
30	0	0	0.0005	5.28%
30	0	0.002	0.0005	6.01%
30	0	0.003	0.0005	6.46%
30	0	0.004	0.0005	6.98%
30	0	0.005	0.0005	7.60%
30	0.1	0	0.0005	5.72%
30	0.1	0.002	0.0005	6.68%
30	0.1	0.003	0.0005	7.29%
30	0.1	0.004	0.0005	8.01%
30	0.1	0.005	0.0005	8.90%
30	0.2	0	0.0005	6.35%
30	0.2	0.002	0.0005	7.68%
30	0.2	0.003	0.0005	8.57%
30	0.2	0.004	0.0005	9.68%
30	0.2	0.005	0.0005	11.10%
30	0.3	0	0.0005	7.32%
30	0.3	0.002	0.0005	9.33%
30	0.3	0.003	0.0005	10.80%

30	0.3	0.004	0.0005	12.79%
30	0.3	0.005	0.0005	15.66%
30	0.4	0	0.0005	8.94%
30	0.4	0.002	0.0005	12.56%
30	0.4	0.003	0.0005	15.67%
30	0.4	0.004	0.0005	20.77%
30	0.4	0.005	0.0005	30.62%

**Table 1c: Raw Data for Production Capacity of 420 within the *demand period***

Production capacity within demand period = 420				
CV	Production cost	Inventory cost	Tardiness cost	Performance
5	0	0	0	-3.84%
5	0	0.002	0	-3.61%
5	0	0.003	0	-3.47%
5	0	0.004	0	-3.30%
5	0	0.005	0	-3.09%
5	0.1	0	0	-4.49%
5	0.1	0.002	0	-4.35%
5	0.1	0.003	0	-4.25%
5	0.1	0.004	0	-4.12%
5	0.1	0.005	0	-3.97%
5	0.2	0	0	-5.39%
5	0.2	0.002	0	-5.42%
5	0.2	0.003	0	-5.44%
5	0.2	0.004	0	-5.45%
5	0.2	0.005	0	-5.42%
5	0.3	0	0	-6.71%
5	0.3	0.002	0	-7.14%
5	0.3	0.003	0	-7.46%
5	0.3	0.004	0	-7.84%
5	0.3	0.005	0	-8.37%
5	0.4	0	0	-8.78%
5	0.4	0.002	0	-10.27%
5	0.4	0.003	0	-11.51%
5	0.4	0.004	0	-13.67%
5	0.4	0.005	0	-18.43%
5	0	0	0.0001	-2.44%
5	0	0.002	0.0001	-1.99%
5	0	0.003	0.0001	-1.70%
5	0	0.004	0.0001	-1.35%

5	0	0.005	0.0001	-0.93%
5	0.1	0	0.0001	-2.88%
5	0.1	0.002	0.0001	-2.42%
5	0.1	0.003	0.0001	-2.12%
5	0.1	0.004	0.0001	-1.74%
5	0.1	0.005	0.0001	-1.25%
5	0.2	0	0.0001	-3.50%
5	0.2	0.002	0.0001	-3.08%
5	0.2	0.003	0.0001	-2.77%
5	0.2	0.004	0.0001	-2.36%
5	0.2	0.005	0.0001	-1.76%
5	0.3	0	0.0001	-4.40%
5	0.3	0.002	0.0001	-4.13%
5	0.3	0.003	0.0001	-3.90%
5	0.3	0.004	0.0001	-3.49%
5	0.3	0.005	0.0001	-2.76%
5	0.4	0	0.0001	-5.83%
5	0.4	0.002	0.0001	-6.06%
5	0.4	0.003	0.0001	-6.15%
5	0.4	0.004	0.0001	-6.26%
5	0.4	0.005	0.0001	-6.42%
5	0	0	0.0002	-0.98%
5	0	0.002	0.0002	-0.27%
5	0	0.003	0.0002	0.18%
5	0	0.004	0.0002	0.72%
5	0	0.005	0.0002	1.38%
5	0.1	0	0.0002	-1.19%
5	0.1	0.002	0.0002	-0.38%
5	0.1	0.003	0.0002	0.16%
5	0.1	0.004	0.0002	0.84%
5	0.1	0.005	0.0002	1.72%
5	0.2	0	0.0002	-1.49%
5	0.2	0.002	0.0002	-0.54%
5	0.2	0.003	0.0002	0.14%
5	0.2	0.004	0.0002	1.05%
5	0.2	0.005	0.0002	2.37%
5	0.3	0	0.0002	-1.91%
5	0.3	0.002	0.0002	-0.79%
5	0.3	0.003	0.0002	0.12%
5	0.3	0.004	0.0002	1.58%
5	0.3	0.005	0.0002	4.09%

5	0.4	0	0.0002	-2.57%
5	0.4	0.002	0.0002	-1.17%
5	0.4	0.003	0.0002	0.39%
5	0.4	0.004	0.0002	3.64%
5	0.4	0.005	0.0002	14.20%
5	0	0	0.0004	2.15%
5	0	0.002	0.0004	3.44%
5	0	0.003	0.0004	4.28%
5	0	0.004	0.0004	5.29%
5	0	0.005	0.0004	6.55%
5	0.1	0	0.0004	2.48%
5	0.1	0.002	0.0004	4.13%
5	0.1	0.003	0.0004	5.26%
5	0.1	0.004	0.0004	6.69%
5	0.1	0.005	0.0004	8.57%
5	0.2	0	0.0004	2.97%
5	0.2	0.002	0.0004	5.21%
5	0.2	0.003	0.0004	6.86%
5	0.2	0.004	0.0004	9.15%
5	0.2	0.005	0.0004	12.56%
5	0.3	0	0.0004	3.74%
5	0.3	0.002	0.0004	7.13%
5	0.3	0.003	0.0004	10.02%
5	0.3	0.004	0.0004	14.82%
5	0.3	0.005	0.0004	24.05%
5	0.4	0	0.0004	5.17%
5	0.4	0.002	0.0004	11.64%
5	0.4	0.003	0.0004	19.49%
5	0.4	0.004	0.0004	36.17%
5	0.4	0.005	0.0004	64.76%
5	0	0	0.0005	3.83%
5	0	0.002	0.0005	5.47%
5	0	0.003	0.0005	6.53%
5	0	0.004	0.0005	7.83%
5	0	0.005	0.0005	9.46%
5	0.1	0	0.0005	4.49%
5	0.1	0.002	0.0005	6.64%
5	0.1	0.003	0.0005	8.12%
5	0.1	0.004	0.0005	10.03%
5	0.1	0.005	0.0005	12.58%
5	0.2	0	0.0005	5.44%

5	0.2	0.002	0.0005	8.50%
5	0.2	0.003	0.0005	10.80%
5	0.2	0.004	0.0005	14.03%
5	0.2	0.005	0.0005	18.99%
5	0.3	0	0.0005	6.97%
5	0.3	0.002	0.0005	11.91%
5	0.3	0.003	0.0005	16.29%
5	0.3	0.004	0.0005	23.88%
5	0.3	0.005	0.0005	38.64%
5	0.4	0	0.0005	9.85%
5	0.4	0.002	0.0005	20.41%
5	0.4	0.003	0.0005	33.33%
5	0.4	0.004	0.0005	53.84%
5	0.4	0.005	0.0005	89.49%
30	0	0	0	-2.95%
30	0	0	0.0001	-1.92%
30	0	0	0.0002	-0.85%
30	0	0	0.0004	1.43%
30	0	0	0.0005	2.66%
30	0.1	0	0	-3.23%
30	0.1	0	0.0001	-2.05%
30	0.1	0	0.0002	-0.80%
30	0.1	0	0.0004	1.88%
30	0.1	0	0.0005	3.33%
30	0.2	0	0	-3.59%
30	0.2	0	0.0001	-2.20%
30	0.2	0	0.0002	-0.72%
30	0.2	0	0.0004	2.52%
30	0.2	0	0.0005	4.31%
30	0.3	0	0	-4.11%
30	0.3	0	0.0001	-2.42%
30	0.3	0	0.0002	-0.59%
30	0.3	0	0.0004	3.51%
30	0.3	0	0.0005	5.83%
30	0.4	0	0	-4.93%
30	0.4	0	0.0001	-2.76%
30	0.4	0	0.0002	-0.38%
30	0.4	0	0.0004	5.20%
30	0.4	0	0.0005	8.51%
30	0	0.002	0	-2.82%
30	0	0.002	0.0001	-1.66%

30	0	0.002	0.0002	-0.45%
30	0	0.002	0.0004	2.17%
30	0	0.002	0.0005	3.58%
30	0.1	0.002	0	-3.09%
30	0.1	0.002	0.0001	-1.74%
30	0.1	0.002	0.0002	-0.30%
30	0.1	0.002	0.0004	2.85%
30	0.1	0.002	0.0005	4.58%
30	0.2	0.002	0	-3.49%
30	0.2	0.002	0.0001	-1.84%
30	0.2	0.002	0.0002	-0.08%
30	0.2	0.002	0.0004	3.87%
30	0.2	0.002	0.0005	6.10%
30	0.3	0.002	0	-4.08%
30	0.3	0.002	0.0001	-1.99%
30	0.3	0.002	0.0002	0.29%
30	0.3	0.002	0.0004	5.59%
30	0.3	0.002	0.0005	8.71%
30	0.4	0.002	0	-5.10%
30	0.4	0.002	0.0001	-2.24%
30	0.4	0.002	0.0002	1.00%
30	0.4	0.002	0.0004	9.07%
30	0.4	0.002	0.0005	14.25%
30	0	0.003	0	-2.73%
30	0	0.003	0.0001	-1.50%
30	0	0.003	0.0002	-0.20%
30	0	0.003	0.0004	2.62%
30	0	0.003	0.0005	4.16%
30	0.1	0.003	0	-3.01%
30	0.1	0.003	0.0001	-1.54%
30	0.1	0.003	0.0002	0.02%
30	0.1	0.003	0.0004	3.47%
30	0.1	0.003	0.0005	5.38%
30	0.2	0.003	0	-3.41%
30	0.2	0.003	0.0001	-1.60%
30	0.2	0.003	0.0002	0.35%
30	0.2	0.003	0.0004	4.78%
30	0.2	0.003	0.0005	7.31%
30	0.3	0.003	0	-4.04%
30	0.3	0.003	0.0001	-1.68%
30	0.3	0.003	0.0002	0.94%

30	0.3	0.003	0.0004	7.14%
30	0.3	0.003	0.0005	10.89%
30	0.4	0.003	0	-5.22%
30	0.4	0.003	0.0001	-1.82%
30	0.4	0.003	0.0002	2.13%
30	0.4	0.003	0.0004	12.51%
30	0.4	0.003	0.0005	19.66%
30	0	0.004	0	-2.63%
30	0	0.004	0.0001	-1.30%
30	0	0.004	0.0002	0.10%
30	0	0.004	0.0004	3.15%
30	0	0.004	0.0005	4.83%
30	0.1	0.004	0	-2.91%
30	0.1	0.004	0.0001	-1.31%
30	0.1	0.004	0.0002	0.40%
30	0.1	0.004	0.0004	4.20%
30	0.1	0.004	0.0005	6.34%
30	0.2	0.004	0	-3.31%
30	0.2	0.004	0.0001	-1.30%
30	0.2	0.004	0.0002	0.90%
30	0.2	0.004	0.0004	5.94%
30	0.2	0.004	0.0005	8.88%
30	0.3	0.004	0	-3.99%
30	0.3	0.004	0.0001	-1.27%
30	0.3	0.004	0.0002	1.79%
30	0.3	0.004	0.0004	9.27%
30	0.3	0.004	0.0005	13.97%
30	0.4	0.004	0	-5.39%
30	0.4	0.004	0.0001	-1.19%
30	0.4	0.004	0.0002	3.87%
30	0.4	0.004	0.0004	18.39%
30	0.4	0.004	0.0005	29.19%
30	0	0.005	0	-2.52%
30	0	0.005	0.0001	-1.08%
30	0	0.005	0.0002	0.43%
30	0	0.005	0.0004	3.77%
30	0	0.005	0.0005	5.62%
30	0.1	0.005	0	-2.78%
30	0.1	0.005	0.0001	-1.02%
30	0.1	0.005	0.0002	0.86%
30	0.1	0.005	0.0004	5.12%

30	0.1	0.005	0.0005	7.53%
30	0.2	0.005	0	-3.18%
30	0.2	0.005	0.0001	-0.92%
30	0.2	0.005	0.0002	1.58%
30	0.2	0.005	0.0004	7.44%
30	0.2	0.005	0.0005	10.93%
30	0.3	0.005	0	-3.92%
30	0.3	0.005	0.0001	-0.72%
30	0.3	0.005	0.0002	2.97%
30	0.3	0.005	0.0004	12.39%
30	0.3	0.005	0.0005	18.64%
30	0.4	0.005	0	-5.60%
30	0.4	0.005	0.0001	-0.12%
30	0.4	0.005	0.0002	6.94%
30	0.4	0.005	0.0004	30.10%
30	0.4	0.005	0.0005	44.42%

Table 1d: Raw Data for Production Capacity of 585 within the *demand period*

Production capacity within demand period = 585				
CV	Production cost	Inventory cost	Tardiness cost	Performance
5	0	0	0.0001	-7.00%
5	0	0.002	0.0001	-6.58%
5	0	0.003	0.0001	-6.22%
5	0	0.004	0.0001	-5.65%
5	0	0.005	0.0001	-5.21%
5	0.1	0	0.0001	-7.24%
5	0.1	0.002	0.0001	-6.66%
5	0.1	0.003	0.0001	-5.98%
5	0.1	0.004	0.0001	-5.79%
5	0.1	0.005	0.0001	-5.04%
5	0.2	0	0.0001	-7.63%
5	0.2	0.002	0.0001	-6.91%
5	0.2	0.003	0.0001	-6.38%
5	0.2	0.004	0.0001	-5.67%
5	0.2	0.005	0.0001	-4.72%
5	0.3	0	0.0001	-7.92%
5	0.3	0.002	0.0001	-7.30%
5	0.3	0.003	0.0001	-6.79%
5	0.3	0.004	0.0001	-5.73%
5	0.3	0.005	0.0001	-4.05%

5	0.4	0	0.0001	-8.72%
5	0.4	0.002	0.0001	-6.94%
5	0.4	0.003	0.0001	-7.26%
5	0.4	0.004	0.0001	-5.10%
5	0.4	0.005	0.0001	1.18%
5	0	0	0.0002	-5.65%
5	0	0.002	0.0002	-4.80%
5	0	0.003	0.0002	-3.94%
5	0	0.004	0.0002	-3.54%
5	0	0.005	0.0002	-2.78%
5	0.1	0	0.0002	-5.56%
5	0.1	0.002	0.0002	-4.40%
5	0.1	0.003	0.0002	-3.64%
5	0.1	0.004	0.0002	-3.09%
5	0.1	0.005	0.0002	-1.83%
5	0.2	0	0.0002	-5.50%
5	0.2	0.002	0.0002	-4.19%
5	0.2	0.003	0.0002	-3.26%
5	0.2	0.004	0.0002	-1.99%
5	0.2	0.005	0.0002	-0.07%
5	0.3	0	0.0002	-4.98%
5	0.3	0.002	0.0002	-3.41%
5	0.3	0.003	0.0002	-2.14%
5	0.3	0.004	0.0002	0.11%
5	0.3	0.005	0.0002	4.28%
5	0.4	0	0.0002	-4.67%
5	0.4	0.002	0.0002	-1.77%
5	0.4	0.003	0.0002	1.87%
5	0.4	0.004	0.0002	7.53%
5	0.4	0.005	0.0002	28.26%
5	0	0	0.0003	-3.90%
5	0	0.002	0.0003	-2.59%
5	0	0.003	0.0003	-2.04%
5	0	0.004	0.0003	-1.08%
5	0	0.005	0.0003	0.09%
5	0.1	0	0.0003	-3.49%
5	0.1	0.002	0.0003	-2.04%
5	0.1	0.003	0.0003	-1.02%
5	0.1	0.004	0.0003	0.26%
5	0.1	0.005	0.0003	1.90%
5	0.2	0	0.0003	-2.91%

5	0.2	0.002	0.0003	-0.86%
5	0.2	0.003	0.0003	0.32%
5	0.2	0.004	0.0003	2.92%
5	0.2	0.005	0.0003	5.54%
5	0.3	0	0.0003	-2.34%
5	0.3	0.002	0.0003	0.77%
5	0.3	0.003	0.0003	3.25%
5	0.3	0.004	0.0003	7.81%
5	0.3	0.005	0.0003	15.80%
5	0.4	0	0.0003	-0.90%
5	0.4	0.002	0.0003	4.69%
5	0.4	0.003	0.0003	11.16%
5	0.4	0.004	0.0003	27.27%
5	0.4	0.005	0.0003	90.05%
5	0	0	0.0004	-2.16%
5	0	0.002	0.0004	-0.64%
5	0	0.003	0.0004	0.32%
5	0	0.004	0.0004	1.46%
5	0	0.005	0.0004	2.89%
5	0.1	0	0.0004	-1.41%
5	0.1	0.002	0.0004	0.66%
5	0.1	0.003	0.0004	1.93%
5	0.1	0.004	0.0004	3.79%
5	0.1	0.005	0.0004	6.25%
5	0.2	0	0.0004	-0.54%
5	0.2	0.002	0.0004	2.32%
5	0.2	0.003	0.0004	4.76%
5	0.2	0.004	0.0004	7.32%
5	0.2	0.005	0.0004	13.25%
5	0.3	0	0.0004	0.83%
5	0.3	0.002	0.0004	5.04%
5	0.3	0.003	0.0004	10.26%
5	0.3	0.004	0.0004	17.64%
5	0.3	0.005	0.0004	31.09%
5	0.4	0	0.0004	3.08%
5	0.4	0.002	0.0004	13.38%
5	0.4	0.003	0.0004	26.79%
5	0.4	0.004	0.0004	46.36%
5	0.4	0.005	0.0004	125.72%
5	0	0	0.0005	-0.37%
5	0	0.002	0.0005	1.26%

5	0	0.003	0.0005	2.85%
5	0	0.004	0.0005	4.17%
5	0	0.005	0.0005	6.34%
5	0.1	0	0.0005	0.64%
5	0.1	0.002	0.0005	3.35%
5	0.1	0.003	0.0005	5.09%
5	0.1	0.004	0.0005	7.69%
5	0.1	0.005	0.0005	11.40%
5	0.2	0	0.0005	2.20%
5	0.2	0.002	0.0005	6.21%
5	0.2	0.003	0.0005	9.27%
5	0.2	0.004	0.0005	13.54%
5	0.2	0.005	0.0005	22.94%
5	0.3	0	0.0005	3.93%
5	0.3	0.002	0.0005	12.14%
5	0.3	0.003	0.0005	17.79%
5	0.3	0.004	0.0005	28.38%
5	0.3	0.005	0.0005	50.51%
5	0.4	0	0.0005	9.75%
5	0.4	0.002	0.0005	24.26%
5	0.4	0.003	0.0005	39.59%
5	0.4	0.004	0.0005	66.13%
5	0.4	0.005	0.0005	211.61%
30	0	0	0.0001	-3.65%
30	0	0	0.0002	-2.58%
30	0	0	0.0003	-1.45%
30	0	0	0.0004	-0.27%
30	0	0	0.0005	0.98%
30	0.1	0	0.0001	-3.76%
30	0.1	0	0.0002	-2.51%
30	0.1	0	0.0003	-1.20%
30	0.1	0	0.0004	0.20%
30	0.1	0	0.0005	1.68%
30	0.2	0	0.0001	-3.89%
30	0.2	0	0.0002	-2.41%
30	0.2	0	0.0003	-0.82%
30	0.2	0	0.0004	0.88%
30	0.2	0	0.0005	2.72%
30	0.3	0	0.0001	-4.08%
30	0.3	0	0.0002	-2.24%
30	0.3	0	0.0003	-0.25%

30	0.3	0	0.0004	1.94%
30	0.3	0	0.0005	4.34%
30	0.4	0	0.0001	-4.38%
30	0.4	0	0.0002	-1.97%
30	0.4	0	0.0003	0.72%
30	0.4	0	0.0004	3.76%
30	0.4	0	0.0005	7.25%
30	0	0.002	0.0001	-3.40%
30	0	0.002	0.0002	-2.18%
30	0	0.002	0.0003	-0.90%
30	0	0.002	0.0004	0.46%
30	0	0.002	0.0005	1.91%
30	0.1	0.002	0.0001	-3.46%
30	0.1	0.002	0.0002	-2.01%
30	0.1	0.002	0.0003	-0.47%
30	0.1	0.002	0.0004	1.18%
30	0.1	0.002	0.0005	2.95%
30	0.2	0.002	0.0001	-3.54%
30	0.2	0.002	0.0002	-1.76%
30	0.2	0.002	0.0003	0.16%
30	0.2	0.002	0.0004	2.25%
30	0.2	0.002	0.0005	4.55%
30	0.3	0.002	0.0001	-3.66%
30	0.3	0.002	0.0002	-1.36%
30	0.3	0.002	0.0003	1.21%
30	0.3	0.002	0.0004	4.08%
30	0.3	0.002	0.0005	7.34%
30	0.4	0.002	0.0001	-3.84%
30	0.4	0.002	0.0002	-0.55%
30	0.4	0.002	0.0003	3.28%
30	0.4	0.002	0.0004	7.86%
30	0.4	0.002	0.0005	13.50%
30	0	0.003	0.0001	-3.24%
30	0	0.003	0.0002	-1.93%
30	0	0.003	0.0003	-0.55%
30	0	0.003	0.0004	0.92%
30	0	0.003	0.0005	2.49%
30	0.1	0.003	0.0001	-3.27%
30	0.1	0.003	0.0002	-1.70%
30	0.1	0.003	0.0003	-0.01%
30	0.1	0.003	0.0004	1.80%

30	0.1	0.003	0.0005	3.76%
30	0.2	0.003	0.0001	-3.31%
30	0.2	0.003	0.0002	-1.34%
30	0.2	0.003	0.0003	0.81%
30	0.2	0.003	0.0004	3.18%
30	0.2	0.003	0.0005	5.81%
30	0.3	0.003	0.0001	-3.35%
30	0.3	0.003	0.0002	-0.70%
30	0.3	0.003	0.0003	2.28%
30	0.3	0.003	0.0004	5.70%
30	0.3	0.003	0.0005	9.67%
30	0.4	0.003	0.0001	-3.41%
30	0.4	0.003	0.0002	0.61%
30	0.4	0.003	0.0003	5.49%
30	0.4	0.003	0.0004	11.60%
30	0.4	0.003	0.0005	19.59%
30	0	0.004	0.0001	-3.05%
30	0	0.004	0.0002	-1.65%
30	0	0.004	0.0003	-0.15%
30	0	0.004	0.0004	1.45%
30	0	0.004	0.0005	3.17%
30	0.1	0.004	0.0001	-3.05%
30	0.1	0.004	0.0002	-1.33%
30	0.1	0.004	0.0003	0.53%
30	0.1	0.004	0.0004	2.55%
30	0.1	0.004	0.0005	4.74%
30	0.2	0.004	0.0001	-3.01%
30	0.2	0.004	0.0002	-0.80%
30	0.2	0.004	0.0003	1.65%
30	0.2	0.004	0.0004	4.37%
30	0.2	0.004	0.0005	7.43%
30	0.3	0.004	0.0001	-2.94%
30	0.3	0.004	0.0002	0.16%
30	0.3	0.004	0.0003	3.74%
30	0.3	0.004	0.0004	7.94%
30	0.3	0.004	0.0005	12.99%
30	0.4	0.004	0.0001	-2.77%
30	0.4	0.004	0.0002	2.42%
30	0.4	0.004	0.0003	9.09%
30	0.4	0.004	0.0004	18.22%
30	0.4	0.004	0.0005	29.23%

30	0	0.005	0.0001	-2.84%
30	0	0.005	0.0002	-1.31%
30	0	0.005	0.0003	0.32%
30	0	0.005	0.0004	2.07%
30	0	0.005	0.0005	3.96%
30	0.1	0.005	0.0001	-2.77%
30	0.1	0.005	0.0002	-0.87%
30	0.1	0.005	0.0003	1.20%
30	0.1	0.005	0.0004	3.47%
30	0.1	0.005	0.0005	5.97%
30	0.2	0.005	0.0001	-2.63%
30	0.2	0.005	0.0002	-0.11%
30	0.2	0.005	0.0003	2.71%
30	0.2	0.005	0.0004	5.91%
30	0.2	0.005	0.0005	9.59%
30	0.3	0.005	0.0001	-2.38%
30	0.3	0.005	0.0002	1.37%
30	0.3	0.005	0.0003	5.82%
30	0.3	0.005	0.0004	11.26%
30	0.3	0.005	0.0005	18.20%
30	0.4	0.005	0.0001	-1.67%
30	0.4	0.005	0.0002	5.65%
30	0.4	0.005	0.0003	16.20%
30	0.4	0.005	0.0004	30.12%
30	0.4	0.005	0.0005	44.46%

## B. Data for Bar Charts and Average Performance Results

The following table contains the data used for Figure-3, 4, 5, 6 and 7.

Table 2: Summary of the data used for bar charts in the numerical results

<b>Production Cost Effect</b>	
<b>Levels</b>	<b>Performance</b>
0	2.25%
0.1	2.69%
0.2	3.46%
0.3	5.16%
0.4	11.33%
<b>Inventory Cost Effect</b>	
<b>Levels</b>	<b>Performance</b>
0	1.66%
0.002	2.92%
0.003	4.06%
0.004	5.92%
0.005	10.34%
<b>Tardiness Cost Effect</b>	
<b>Levels</b>	<b>Performance</b>
0.0001	-1.35%
0.0002	1.06%
0.0003	4.01%
0.0004	8.59%
0.0005	12.58%
<b>Effect of Production Capacity. within Demand Period</b>	
<b>Levels</b>	<b>Performance</b>
140	4.69%
280	7.36%
420	3.24%
585	4.63%
<b>Stochasticity Effect</b>	
<b>Levels</b>	<b>Performance</b>
0.05	3.75%
0.3	5.55%

**Table 3: Summary of average performance results**

Prod. cap. within demand period=140	Prod. cap. within demand period=140						
	CV=30	Production cost	Performance	Inventory cost	Performance	Tardiness cost	Performance
Prod. cap. within demand period=280	CV=5	0	4.88%	0	4.14%	0.0001	2.35%
		0.1	4.87%	0.002	4.52%	0.0002	3.42%
		0.2	4.90%	0.003	4.86%	0.0003	4.55%
		0.3	5.04%	0.004	5.43%	0.0004	7.00%
		0.4	6.00%	0.005	6.73%	0.0005	8.37%
Prod. cap. within demand period=420	CV=5	Production cost	Performance	Inventory cost	Performance	Tardiness cost	Performance
		0	3.88%	0.00%	3.64%	0.0001	2.30%
		0.1	3.96%	0.20%	3.95%	0.0002	3.07%
		0.2	4.09%	0.30%	4.18%	0.0003	3.86%
		0.3	4.34%	0.40%	4.49%	0.0004	5.54%
Prod. cap. within demand period=280	CV=30	Production cost	Performance	Inventory cost	Performance	Tardiness cost	Performance
		0	5.55%	0	4.32%	0.0001	2.21%
		0.1	6.05%	0.002	6.05%	0.0002	5.05%
		0.2	6.91%	0.003	7.54%	0.0003	8.38%
		0.3	8.81%	0.004	10.16%	0.0004	12.08%
Prod. cap. within demand period=420	CV=5	Production cost	Performance	Inventory cost	Performance	Tardiness cost	Performance
		0	4.28%	0	4.28%	0.0001	1.99%
		0.1	4.66%	0.002	4.66%	0.0002	3.79%
		0.2	5.26%	0.003	5.26%	0.0003	5.75%
		0.3	6.36%	0.004	6.36%	0.0004	7.89%
Prod. cap. within demand period=280	CV=30	Production cost	Performance	Inventory cost	Performance	Tardiness cost	Performance
		0	1.21%	0	-0.37%	0.0001	-6.63%
		0.1	1.54%	0.002	1.31%	0.0002	-3.27%
		0.2	2.22%	0.003	2.93%	0.0003	0.85%
		0.3	4.17%	0.004	5.60%	0.0004	11.30%
Prod. cap. within demand period=420	CV=5	Production cost	Performance	Inventory cost	Performance	Tardiness cost	Performance
		0	0.48%	0	0.23%	0.0001	-3.68%
		0.1	0.89%	0.002	1.33%	0.0002	-1.57%
		0.2	1.57%	0.003	2.18%	0.0003	0.81%
		0.3	2.93%	0.004	3.46%	0.0004	6.74%

		0.4	6.82%	0.005	5.48%	0.0005	10.38%
Prod. cap. within demand period=585	CV=30	<b>Production cost</b>	<b>Performance</b>	<b>Inventory cost</b>	<b>Performance</b>	<b>Tardiness cost</b>	<b>Performance</b>
		0	-1.79%	0	-2.50%	0.0001	-6.05%
		0.1	-0.57%	0.002	0.60%	0.0002	-1.17%
		0.2	1.60%	0.003	3.46%	0.0003	5.95%
		0.3	6.60%	0.004	8.19%	0.0004	12.81%
	CV=5	<b>Production cost</b>	<b>Performance</b>	<b>Inventory cost</b>	<b>Performance</b>	<b>Tardiness cost</b>	<b>Performance</b>
		0	-0.46%	0	-0.44%	0.0001	-3.25%
		0.1	0.15%	0.002	0.94%	0.0002	-0.84%
		0.2	1.14%	0.003	2.04%	0.0003	1.98%
		0.3	3.08%	0.004	3.64%	0.0004	5.32%
		0.4	8.42%	0.005	6.15%	0.0005	9.13%

## C. The Data for Endogenous Variable Number of Due-dates

Table-4 contains the data, number of due-dates and the corresponding profit in Contract *DTDP*, for Figure-2.

**Table 4: The data illustrating the effect of number of due-dates on the profit in Contract *DTDP***

Number of Due-dates	Profit Contract DTDP	Number of Due-dates	Profit Contract DTDP	Number of Due-dates	Profit Contract DTDP	Number of Due-dates	Profit Contract DTDP
2	275.35	24	321.41	46	323.89	68	327.34
3	299.65	25	322.15	47	322.61	69	325.21
4	293.22	26	321.27	48	327.61	70	328.19
5	304.30	27	324.12	49	328.49	71	328.31
6	305.61	28	306.99	50	325.90	72	328.12
7	297.38	29	314.37	51	327.03	73	327.60
8	311.35	30	315.52	52	326.41	74	328.27
9	316.26	31	315.24	53	324.53	75	327.19
10	308.99	32	317.61	54	324.12	76	329.57
11	320.82	33	325.99	55	330.65	77	330.11
12	317.43	34	323.04	56	324.51	78	328.67
13	318.46	35	320.71	57	326.01	79	327.85
14	302.65	36	322.79	58	325.91	80	327.17
15	315.09	37	323.67	59	327.09	81	327.80
16	317.58	38	327.05	60	326.37	82	329.46
17	317.78	39	324.47	61	325.34	83	324.03
18	316.26	40	323.51	62	321.49	84	326.78
19	323.03	41	327.33	63	328.75	85	328.03
20	317.56	42	325.93	64	326.65	86	326.27
21	322.80	43	325.57	65	327.44	87	327.47
22	325.74	44	328.40	66	328.39	88	330.68
23	320.45	45	326.36	67	326.72	89	326.81