# CHAPTER 5

# A SINGLE MANUFACTURER AND MULTI-RETAILERS' SUPPLY CHAIN

In reality, a seller (or the manufacture in our case) usually has a chance to sell its product to more than one buyer (or the retailers in our case). In some situations, the assumption of having only one buyer may not be so realistic, especially when the manufacture has a higher bargaining power who has an ability to supply its product to more than one retailer. The main reason for this is to add the context of the distribution strategy to the existing problem. With the multi-echelon inventory supply chain model with multi-buyers under the make to stock environment, if any shortage exists either from erroneous demand forecasting or supply shortages or long lead times, the manufacturer must make a distributing decision to spread out a portion of available units to certain retailers. Since any shortage or unfulfilled retailer demand can lead to the penalty cost that the manufacturer has to pay to that retailer. This strategy depends on each company's policy where the priority of each retailer must be set.

In this chapter, the multi-echelon supply chain is studied under three controlling policies, which are the centralized controlling policy under manufacturer domination, centralized controlling policy under the entire chain's perspective and coordinating controlling policy.

## 5.1 Members in the Single Manufacturer and Multi-Retailers' Supply Chain

The chain in the study consists of one supplier, one manufacturer, *N*-retailers and end customers. Each of these facilities is a representative of different supply chain echelons. However, this paper only focuses on a relationship formed between a manufacturer and *N*-retailers (supplier and end customers are considered as external members in the system when considering the profit of the chain) as shown in Figure 5.1. Inventories among members in the chain are controlled by the periodic review under the make-to-stock environment, in which the uncertain demand and lead-times are considered. Descriptions of the manufacturer and retailers are as follows:

### 5.1.1 Manufacturer

The manufacturer has to decide its optimal Lot Sizing policy (*DLS*) and the safety stock level (*Optss*) to control its inventory. Under *DLS*, the manufacturer must decide in its ordering plan, whether to make an order following the lot for lot, or to combine its orders and make a bigger purchasing batch size. Having received raw materials from the supplier, the manufacturer then transforms them to the finished products and distributes them to *N*-retailers. Each retailer penalizes any unfulfilled demand from the manufacturer as the shortage cost. Therefore, the manufacturer holds some safety stock to cover an effect of uncertainty in customer demand and delivery lead-time. The safety stock will be used only when a normal inventory level cannot satisfy the customer demand and it must be filled as soon as possible after having been used.

### 5.1.2 Retailers

Each retailer aims to determine their optimal target stock level ($OptS_r$) to control their inventory. The target stock level of the retailers is not only to cover the end customer's demand but also to cover the effect of end customer demand's fluctuation as well as the late delivery and unfulfilled quantity from the manufacturer. Each retailer reviews its inventory and makes an order at every interval time $Tp$.

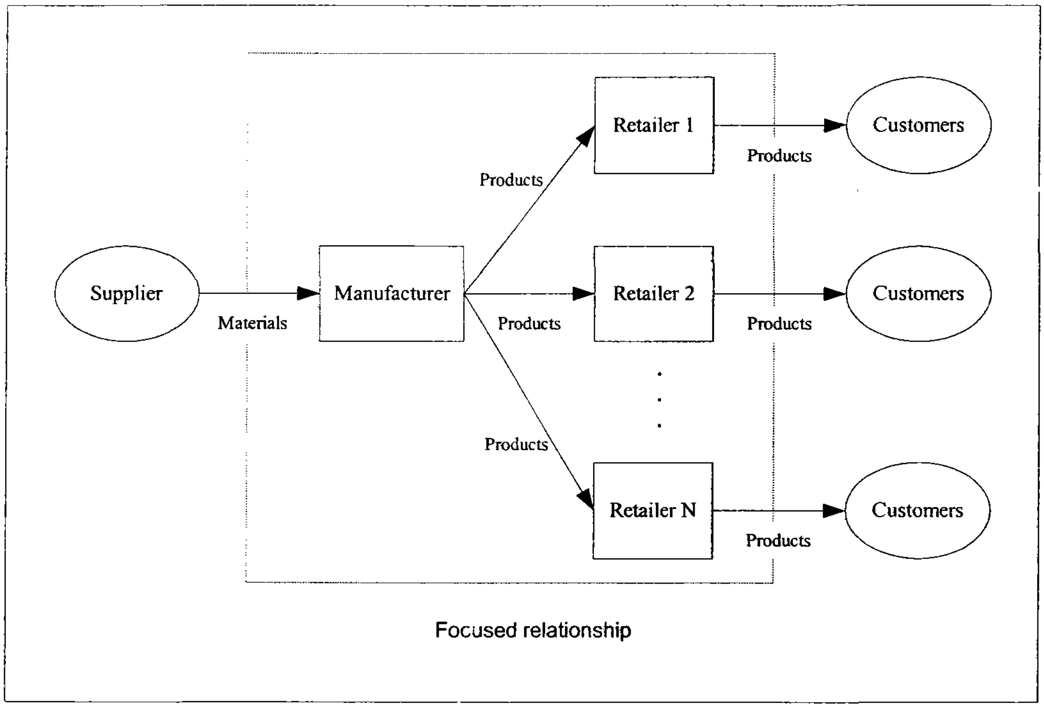


Figure 5.1 Members in a single manufacturer and multi-retailers' supply chain

## 5.2 Assumptions

The following assumption will be used in all models in this chapter.

1. The manufacturer uses the periodic review and lot sizing policy to control its inventory.
2. All retailers use the periodic review with target stock level ($T$, $S$) to control their inventories.
3. End customer's demand and delivery lead time are randomly generated based on the normal distribution.
4. For both manufacturer and retailers, only one order is allowed to be outstanding at any period.
5. Production rate of the manufacturer is assumed to be fixed and higher than the mean demands from all retailers at each period.
6. Only a single product is considered. Without loss of the generality, the manufacturer uses one unit of raw material to produce one unit of the finished product.
7. Unfulfilled demand is considered to be shortage.
8. Supplier has unlimited capacity.

9. Since the supplier is not of interest in this dyadic relationship, the shortage cost paid by the supplier to the manufacturer is not included in the profit function of the chain.
10. This is no transportation cost and in-transit holding cost in the profit function.

## 5.3 Notations used in the Single Manufacturer and Multi-Retailers' Supply Chain

The following notations will be used in all models.

### 5.3.1 Random Variables

| | |
|---|---|
| $r$ | = 1,2,...,$N$ represent retailer index. |
| $t$ | = 1,2,...,$T$ represent period index. |
| $D_{rt}$ | = End customer demand at retailer $r$ at period $t$ (units/day) |
| $FD_t$ | = Forecasted demand at the manufacturer at period $t$ (units/day) |
| $LT\_sm$ | = Delivery lead time from the supplier to the manufacturer (days) |
| $LT\_mr$ | = Delivery lead time from the manufacturer to each retailer (day) |
| $Latem_{rt}$ | = Late time delivery from the manufacturer to retailer $r$ at period $t$ (days) |
| $ESR_{rt}$ | = Ending stock on hand level of finished products at retailer $r$ at period $t$ (units) |
| $Ess_t$ | = Ending safety stock level of finished products at the manufacturer at period $t$ (units) |
| $Es_t$ | = Ending stock on hand level of raw materials at the manufacturer at period $t$ (units) |
| $EI_t$ | = Ending stock on hand level of finished products at the manufacturer at period $t$ (units) |
| $Qor_{rt}$ | = Ordering quantity of retailer $r$ at period $t$ (units) |
| $Qm_t$ | = Ordering quantity of the manufacturer at period $t$ (units) |
| $Qpro_t$ | = Production quantity of the manufacturer at period $t$ (units) |
| $QsellR_{rt}$ | = Sales volume per period at retailer $r$ at period $t$ (units) |
| $QsellM_{rt}$ | = Sales volume per period at the manufacturer to retailer $r$ at period $t$ (units) |
| $ShortQm_{rt}$ | = Shortage quantity at the manufacturer at period $t$ (units) |
| $RShortQ_{rt}$ | = Shortage quantity at retailer $r$ at period $t$ (units) |
| $Cact\_m_{rt}$ | = Activated cost at the manufacturer that is paid to push an on time delivery to retailer $r$ at period $t$ (\$) |
| $Corder\_m_t$ | = Ordering cost of the manufacturer at period $t$ (\$) |
| $Corder\_r_{rt}$ | = Ordering cost of retailer $r$ at period $t$ (\$) |
| $Bonus_{rt}$ | = Bonus of retailer $r$ that is paid to the manufacturer at period $t$ (\$) |
| $Cp_{rt}$ | = Sales price per unit of the product at the manufacturer to retailer $r$ at period $t$ under the quantity discount scheme (\$/unit) |
| $FR_{rt}$ | = Fill rate of retailer $r$ at period $t$ (%) |
| $FRm_{rt}$ | = Fill rate of the manufacturer to retailer $r$ at period $t$ (%) |
| $\beta$ | = Desired customer service level or desired fill rate (%) |
| $\Pi s$ | = Total profit of the supply chain (\$) |
| $\Pi m$ | = Profit of the manufacturer (\$) |
| $\Pi r_r$ | = Profit of retailer $r$ (\$) |
| $\Pi rs$ | = Total profit of all retailers in the chain (\$) |
| $\Pi joint$ | = Total joint profit of the manufacturer and the retailers (\$) |
| $\Pi_m^C$ | = Profit of the manufacturer in the coordinated controlling system (\$) |
| $\Pi_{r_r}^C$ | = Profit of retailer $r$ in the coordinated controlling system (\$) |

$\Pi_r^C$ = Total profit of all retailers in the coordinated controlling system ($)

### 5.3.2 Pre-determined Variables

$T$ = Planning horizon (periods)
$Tp$ = Duration of each period (days)
$N$ = Number of retailers
$PR$ = Production rate per day at the manufacturer (units/day)
$LTC\_sm$ = Delivery lead time contract form between the supplier and the manufacturer (days)
$LTC\_mr$ = Delivery lead time contract form between the manufacturer and the retailers (days)
$Sell_r$ = Sales price per unit of finished products at retailer *r* ($/unit)
$Cp_r$ = Sales price per unit of the product at the manufacturer to retailer *r* ($/unit)
$Ch\_m$ = Unit holding cost of finished product at the manufacturer ($/unit/period)
$Ch\_rmtl$ = Unit holding cost of raw material at the manufacturer ($/unit/period)
$Ch\_r_r$ = Unit holding cost of finished product at retailer *r* ($/unit/period)
$Cs\_m_r$ = Unit shortage cost at the manufacturer that is paid to retailer *r* ($/unit)
$Cs\_r_r$ = Unit shortage cost at retailer *r* ($/unit)
$Cpm$ = Unit purchasing cost at the manufacturer ($/unit)
$Cpr\_m$ = Unit production cost at the manufacturer ($/unit)
$Ca\_r_r$ = Unit administration cost at retailer *r* ($/unit)
*bonus* = Bonus cost per period at each retailer ($/period)
$Cac\_m$ = Activated cost per period at the manufacturer ($/unit)
$ER_r$ = Pre-determined quantity discount level for retailer *r* (units)

### 5.3.3 Decision Variables

There are six decision variables to decide in the study. The notations can be shown as:

$DLS$ = Discrete lot sizing at the manufacturer (ordering policy)
$Optss$ = Safety stock level at the manufacturer (units)
$OptS_r$ = Target stock level at retailer *r* (units)
$ACB_r$ = Decision to accept or reject bonus offered by retailer *r* of the manufacturer
$EQ_r$ = Percentage of exceeding units' quantity discount offered by the manufacturer to retailer *r* (%)
$DS_r$ = Percentage of distributing the products on hand from the manufacturer to retailer *r* (%)

### 5.3.4 Genetic Algorithm Parameters

$k$ = $1,2,\ldots,k_{max}$ represent generation index.
$s$ = $1,2,\ldots,S$ represent chromosome index.
$k_{max}$ = Stopping generation or termination (generations)
$S$ = Population size (chromosomes)
$P(k)$ = Population of generation $k$
$P_c$ = Probability of crossover
$P_m$ = Probability of mutation

### 5.4 Strategic Management in the Single Manufacture and Multi-Retailers' Supply Chain

For comparison purposes, the models in this chapter are constructed and separable according to each perspective, which are the centralized controlling policy under manufacturer domination, the entire chain's perspective, and lastly coordinating controlling policy with an incentive scheme.

#### 5.4.1 Centralized Controlling Policy under the Manufacturer Domination

From the results of Chapter 4 (a singly dyadic supply chain), it was obviously seen that without information sharing under the decentralized controlling policy, the system faced with the problems of forecasting error and inefficient use of inventory at each member. As a consequence, the profit of the chain under the decentralized controlling policy is inferior to the profit generated from the centralized and coordinating controlling policies. Since the decentralized controlling policy without information sharing has proven to be a week strategic management. Therefore, this chapter only focuses on the centralized and coordinating controlling policies (all with full information sharing).

Under this policy, the chain is created using full information sharing, demanding that information of the end customers is available to all parties so that minimum error in setting the manufacturer's production level can be achieved. This is to avoid multiple demand forecast updates and make demand data downstream, available to the upstream site. However, under the manufacturer domination, the system aims at maximizing the profit of the manufacturer and represents the situation where the manufacturer can dominate the chain in which the retailers may not be totally happy to join the chain. We use the profit of the manufacturer from this case to be the profit base line for justifying the win-win situation when comparing with other perspectives.

Objective function of centralized controlling policy under the manufacturer domination

*Maximize profit of the manufacturer ($\Pi m$)*

Profit of the manufacturer *($\Pi m$)* = Revenues of the manufacturer
- Total operating costs of the manufacturer

Revenues of the manufacturer = Sales price x Sales volume of the manufacturer

Total operating costs of the manufacturer = Holding cost of raw material
+ Holding cost of finished product
+ Penalty cost
+ Ordering cost
+ Purchasing cost of raw material
+ Production cost

where:

$$\Pi m = \sum_{r=1}^{N}\sum_{t=1}^{T} Cp_r \times QsellM_{rt} - \sum_{t=1}^{T} Ch\_rmtl \times Es_t - \sum_{t=1}^{T} Ch\_m \times (EI_t + Ess_t)$$

$$- \sum_{r=1}^{N}\sum_{t=1}^{T} Cs\_m_r \times ShortQm_{rt} - \sum_{t=1}^{T} Corder\_m_t - \sum_{t=1}^{T} Cpm \times Qm_t \qquad (55)$$

$$- \sum_{t=1}^{T} Cpr\_m \times Qpro_t$$

Subject to:

$$FRm_{rt} = 1 - (ShortQm_{rt} / Qor_{rt}) \qquad (55)$$

$$FRm_{rt} \geq \beta \qquad (56)$$

For $r = 1, 2\ldots,N$ and $t = 1,2\ldots,T$.

### 5.4.2 Centralized Controlling Policy under the Entire Chain's perspective

Centralized controlling policy under the entire chain's perspective is the system operating under one controller. This controlling p olicy would be e asier to implement if all members in the chain belong to only one owner, since it is quite difficult in practice for companies with different interests to be joined b y a single entity and attain centralization. Thus, the objective of this policy is to maximize the profit of the entire chain rather than one member in particular.

Objective of the centralized controlling policy under the entire chain's perspective

*Maximize profit of the supply chain ($\Pi s$)*

Profit of the supply chain ($\Pi s$) = Profit of the manufacturer ($\Pi m$)
+ Total profit of the retailers ($\Pi rs$)

Profit of retailer $r$ ($\Pi r_r$) = (Sales price of the retailer x Sales volume of the retailer)
+ (Unit shortage cost x Quantity of shortage of the manufacturer)
- Holding cost of the finished product
- Opportunity shortage cost + Ordering cost
- Purchasing cost of the finished p
- Administration cost

Total profit of the retailers ($\Pi rs$) = Profit of retailer 1
+ Profit of retailer 2
+ … + Profit of retailer $N$

where:

$$\Pi m = \sum_{r=1}^{N}\sum_{t=1}^{T} Cp_r \times QsellM_{rt} - \sum_{t=1}^{T} Ch\_rmtl \times Es_t - \sum_{t=1}^{T} Ch\_m \times (EI_t + Ess_t)$$
$$- \sum_{r=1}^{N}\sum_{t=1}^{T} Cs\_m_r \times ShortQm_{rt} - \sum_{t=1}^{T} Corder\_m_t - \sum_{t=1}^{T} Cpm \times Qm_t$$
$$- \sum_{t=1}^{T} Cpr\_m \times Qpro_t \qquad (57)$$

$$\Pi rs = \left(\sum_{r=1}^{N}\sum_{t=1}^{T} Sell_r \times QsellR_{rt} + \sum_{r=1}^{N}\sum_{t=1}^{T} Cs\_m_r \times ShortQm_{rt}\right)$$
$$- \sum_{r=1}^{N}\sum_{t=1}^{T} Ch\_r_r \times ESR_{rt} - \sum_{r=1}^{N}\sum_{t=1}^{T} Cs\_r_r \times RshortQ_{rt} \qquad (58)$$
$$- \sum_{r=1}^{N}\sum_{t=1}^{T} Corder\_r_{rt} - \sum_{r=1}^{N}\sum_{t=1}^{T} Cp_r \times QsellM_{rt}$$
$$- \sum_{r=1}^{N}\sum_{t=1}^{T} Ca\_r_r \times QsellR_{rt}$$

Subject to:

$$FR_{rt} = 1 - (RshortQ_{rt} / D_{rt}) \qquad (59)$$

$$FR_{rt} >= \beta \qquad (60)$$

For $r = 1, 2\ldots,N$ and $t = 1,2\ldots,T$.

### 5.4.3 Coordinating the Controlling Policy with an Incentive Scheme

As mentioned in the previous section, the coordinating controlling policy with an incentive scheme occurs when a strong relationship is formed between the manufacturer and the retailers. Each member in the chain intends to share the information at the point of sales and exchange an incentive to strengthen their relationship. In practice, such information sharing can hardly be achieved without the incentive offering (as a start) and full cooperation of all parties in the chain. Therefore, each member should contribute some forms of incentive to their partner as a means of strengthening their relationship and improving the performance of the supply chain, as well as their own companies. As a result, the objective of this policy is not only to maximize the total profit of the supply chain system but also to strengthen relationships which can lead to an improvement of the overall channel profitability. However each member in the chain still has the authority to accept or reject the incentives offered by its partners.

The results from the previous chapter (a single dyadic supply chain) present that the two-sided incentive outperformed the one-sided incentive and can increase the profitability of the chain. In additional, it can also balance the profit increment among the members in the chain. Therefore, only two-sided incentive will be considered in the following study. Since the exceeding units' quantity discount and bonus are the most popular and most frequent discuss and implementation in the material management in textbooks (i.e., Stevenson, 1986, Schonberger and Knod, 1991) and research works (i.e., Abad, 1988, Guder *et al.* 1994, Tersine *et al.* 1995, Weng, 1995, Khouja and Mehrez, 1996, Chung *et al.*, 1996, Lin and Kroll, 1997, Khouja, 2000, Matsuyama, 2001, Rubin and Benton, 2003). In addition, EUQD&Bonus presented the worst case scenario (lowest chain profit) among the two-sided incentive policies. So we use this as the bottom line model to represent the two-sided incentive policy. EUQD&Bonus scheme is a case where the manufacturer offers the discount to the retailers for each unit purchased beyond the pre-determined quantity discount level ($ER_r$) and reciprocally the retailers offer a bonus to the manufacturer as an exchange in order to speed up its delivery. As a consequence, the bonus is paid to the manufacturer only when the products are delivered to each retailer at correct quantity and on time. In order to deliver the product on time, the manufacturer may need to pay an extra cost which is called "the activated cost" to gain extra effort for such activities.

Objective of coordinating controlling policy with an incentive scheme

*Maximize total joint profit of the chain* ($\Pi_{joint}$)

Total joint profit of the chain ($\Pi_{joint}$) = Profit of the manufacturer ( $\Pi_m^C$ )

+ Total profits of the retailers ( $\Pi_r^C$ )

Profit of the manufacturer ( $\Pi_m^C$ )

= (Sales price per unit at the manufacturer x Sales volume of the manufacturer)
+ **Bonus** - Holding cost of raw material - Holding cost of finished product
- Penalty cost - Ordering cost - Purchasing cost of raw material
- Production cost - **Activated cost**

$$
\begin{aligned}
\Pi_m^C = & \sum_{r=1}^{N}\sum_{t=1}^{T} Cp_{rt} \times QsellM_{rt} + \sum_{r=1}^{N}\sum_{t=1}^{T} Bonus_{rt} \\
& - \sum_{t=1}^{T} Ch\_rmtl \times Es_t - \sum_{t=1}^{T} Ch\_m \times (EI_t + Ess_t) \\
& - \sum_{r=1}^{N}\sum_{t=1}^{T} Cs\_m_r \times ShortQm_{rt} - \sum_{t=1}^{T} Corder\_m_t \\
& - \sum_{t=1}^{T} Cpm \times Qm_t - \sum_{t=1}^{T} Cpr\_m \times Qpro_t \\
& - \sum_{r=1}^{N}\sum_{t=1}^{T} Cact\_m_{rt}
\end{aligned} \tag{61}
$$

Profit of retailer $r$ $(\Pi_{r_r}^C)$

= (Sales price per unit of the retailer x Sales volume of the retailer)
\+ Penalty cost paid by the manufacturer for unfulfilled retailer's demand
\- Holding cost of the finished product
\- Opportunity shortage cost - Ordering cost
\- Purchasing cost of the finished product - Administration cost - **Bonus**

Total profit of the retailers $(\Pi_r^C)$ = Profit of retailer 1
\+ Profit of retailer 2
\+ ... + Profit of retailer $N$

$$
\begin{aligned}
\Pi_r^C = & \left(\sum_{r=1}^{N}\sum_{t=1}^{T} Sell_r \times QsellR_{rt} + \sum_{r=1}^{N}\sum_{t=1}^{T} Cs\_m_r \times ShortQm_{rt}\right) \\
& - \sum_{r=1}^{N}\sum_{t=1}^{T} Ch\_r_r \times ESR_{rt} - \sum_{r=1}^{N}\sum_{t=1}^{T} Cs\_r_r \times RshortQ_{rt} \\
& - \sum_{r=1}^{N}\sum_{t=1}^{T} Corder\_r_{rt} - \sum_{r=1}^{N}\sum_{t=1}^{T} Cp_{rt} \times QsellM_{rt} \\
& - \sum_{r=1}^{N}\sum_{t=1}^{T} Ca\_r_r \times QsellR_{rt} - \sum_{r=1}^{N}\sum_{t=1}^{T} Bonus_{rt}
\end{aligned} \tag{62}
$$

Subject to:

$$Cp_{rt} = \begin{cases} Cp_r & \text{if } Qor_{rt} \le ER_r \\ ((Cp_r \times ER_r) + (Cp_r)(Qor_{rt} - ER_r)(1-(EQ_r / 100)))/Qor_{rt} & \text{otherwise} \end{cases} \quad (63)$$

$$Bonus_{rt} = \begin{cases} bonus & \text{if } Latem_{rt} \le 0 \text{ and } shortQm_{rt} = 0 \text{ and } ACB_r \text{ is accepted} \\ 0 & \text{otherwise} \end{cases} \quad (64)$$

$$Cact\_m_{rt} = \begin{cases} Cac\_m & \text{if } Latem_{rt} > 0 \text{ and } ACB_r \text{ is accepted} \\ 0 & \text{otherwise} \end{cases} \quad (65)$$

$$FR_{rt} \quad >= \quad \beta \quad (66)$$

For $r = 1, 2\ldots,N$ and $t = 1,2\ldots,T$.

## 5.5 Numerical Example of the Single Manufacturer and Multi-Retailers' Supply Chain

Another example is built to demonstrate the proposed algorithms and to compare the results under three controlling policies: the centralized controlling policy under the manufacturer domination, the entire chain's perspective, and the coordinating controlling policy with an incentive scheme. Table 5.1 presents the parameters used in the chapter.

Under a make to stock environment, the manufacturer has to produce the products and supply them to the retailers based on its forecasted demand ($FD_t$). On the other hand, end customer demands ($D_{rt}$) are generated at the retailers. The mean and standard deviation of the forecasted demand at the manufacturer are based on the summation of end customer's demand at each retailer. This is due to the fact that the demand information can be passed to all members in the chain. The end customer's demand at each retailer ($D_{rt}$) is randomly generated based on the normal distribution, in which approximately 25% of their mean value is considered as its standard deviation.

With one manufacturer and three retailers ($N=3$) in this study, the mean and variance of the end customer's demand at retailer 1 is the highest, followed by those of retailer 3 and retailer 2. Each retailer is distinguished by their different characteristics as they mark up the profit as illustrated in Table 5.2. As a result, the sales price of the manufacturer to each retailer is different, and so is the sales price of each retailer to their customers. In general, the manufacturer gains the highest profit margin from retailer 1, whereas retailer 3 gains the highest profit margin from its customers. Due to problems of uncertainty in the demand and lead-time, the number of products available on hand at the manufacturer at any period may be insufficient to supply all retailers as requested and needs to be proportionally distributed to each retailer following the objective set in each perspective. As each retailer has different characteristics, the percentage of distributing the products on hand to each retailer is also one of the decision variables optimized by using the Genetic Algorithm's approach.

Table 5.1 Input Data for the numerical example of a single manufacturer and multi-retailers' supply chain

| Input parameters | Set values |
|---|---|
| End customer demand per day at retailer 1 ($D_{1t}$)<br>End customer demand per day at retailer 2 ($D_{2t}$)<br>End customer demand per day at retailer 3 ($D_{3t}$) | Normal (100, $25^2$)* units<br>Normal (50, $12^2$)* units<br>Normal (75, $15^2$)* units |
| Forecasted end customer demand per period ($FD_t$) | Normal (225, $32^2$)* × *Tp* units |
| Delivery lead time from the supplier (*LT_sm*) | Normal (2, 1)* days |
| Delivery lead time from the manufacturer (*LT_mr* | Normal (2, 1)* days |
| Delivery lead time contract from the supplier (*LTCsm*) | 2 days |
| Delivery lead time contract from the manufacturer (*LTC_mr*) | 2 days |
| Production rate per day (*PR*) | 300 units |
| Planning horizon (*T*) | 6 periods |
| Number of days in each period (*Tp*) | 10 days |
| Required service level ($\beta$) | 90 % |
| Quantity discount level under EUQD policy offered from the manufacturer to retailer 1 ($ER_1$)<br>Quantity discount level under EUQD policy offered from the manufacturer to retailer 2 ($ER_2$)<br>Quantity discount level under EUQD policy offered from the manufacturer to retailer 3 ($ER_3$) | 1,450<br>700<br>1,100 |
| **Cost parameters** | **Set values** |
| Sales price per unit of raw material from the supplier (*Cpm*) | $150 per unit |
| Unit holding cost of raw material at the manufacturer per period (*Ch_rmtl*) | 1.5% of raw material value |
| Sales price per unit of the product at the manufacturer to retailer 1 ($Cp_1$)<br>Sales price per unit of the product at the manufacturer to retailer 2 ($Cp_2$)<br>Sales price per unit of the product at the manufacturer to retailer 3 ($Cp_3$) | $615 per unit<br>$610 per unit<br>$605 per unit |
| Unit production cost at the manufacturer (*Cpr_m*) | $350 per unit |
| Unit holding cost of product at the manufacturer and the retailers per period (*Ch_m*,and $Ch\_r_r$) | 2% and 3%of product value |
| Ordering cost at the manufacturer and the retailers (*Corder_m*,and $Corder\_r_r$) | $500 per order |
| Unit shortage cost paid by the manufacturer to retailer 1 ($Cs\_m_1$)<br>Unit shortage cost paid by the manufacturer to retailer 2 ($Cs\_m_2$)<br>Unit shortage cost paid by the manufacturer to retailer 3 ($Cs\_m_3$) | $20 per unit<br>$15 per unit<br>$10 per unit |
| Unit opportunity shortage cost at retailer 1 ($Cs\_r_1$)<br>Unit opportunity shortage cost at retailer 2 ($Cs\_r_2$)<br>Unit opportunity shortage cost at retailer 3 ($Cs\_r_3$) | $35 per unit<br>$30 per unit<br>$40 per unit |
| Unit administration cost at retailer 1 ($Ca\_r_1$)<br>Unit administration cost at retailer 2 ($Ca\_r_2$)<br>Unit administration cost at retailer 3 ($Ca\_r_3$) | $50 per unit<br>$60 per unit<br>$50 per unit |
| Sales price per unit of finished product at retailer 1 ($Sell_1$)<br>Sales price per unit of finished product at retailer 2 ($Sell_2$)<br>Sales price per unit of finished product at retailer 3 ($Sell_3$) | $750 per unit<br>$745 per unit<br>$755 per unit |
| Bonus cost per period offered by each retailer to the manufacturer (*bonus*) | $ 10,000 per period |
| Activated cost per period at the manufacturer (*Cac_m*) | $ 2,000 per period |
| **GA parameters** | **Set values** |
| Number of chromosomes in the population (*S*) | 10 chromosomes |
| Probability of crossover (*Pc*) | 50% |
| Probability of mutation (*Pm*) | 20% |
| Stopping generation ($k_{max}$) | 10,000 generations |

* Normal (mean, standard deviation$^2$)

Table 5.2 Different characteristics among the retailers in the numerical example

| Different Characteristics of each retailer | Retailer 1 | Retailer 2 | Retailer 3 |
|---|---|---|---|
| End customer demand per day at each retailer (units) | Normal (100, $25^2$)* | Normal (50, $12^2$)* | Normal (75, $15^2$)* |
| Sales price per unit of product at the manufacturer to each retailer ($) | 615 | 610 | 605 |
| Sales price per unit of product at each retailer ($) | 750 | 745 | 755 |
| Unit shortage cost paid by the manufacturer to each retailer ($) | 20 | 15 | 10 |
| Unit opportunity of shortage cost at each retailer ($) | 35 | 30 | 40 |
| Administration cost at each retailer ($) | 50 | 60 | 50 |
| Approximate percentage of profit margin of selling one unit of product at the manufacturer (%) | 20.06 | 19.08 | 18.11 |
| Approximate percentage of profit margin of selling one unit of product at each retailer (%) | 9.50 | 7.96 | 11.91 |

* Normal (mean, standard deviation$^2$)

## 5.6 Solving the problems by Genetic Algorithm

This paper studies a supply chain system where a manufacturer distributes a single product to *N*-retailers (*N*=3), who in turn sell the product to end customers. Since the end customer demand and delivery lead-time are uncertain, the optimal settings for all six decision variables are needed to be determined by the Genetic Algorithm (GA).

### 5.6.1 First step: Setting the Lower Bound and Upper Bound for the Solution

This boundary is set to limit the computational time for the GA algorithm. However, the searching boundary for each decision variable must be large enough to ensure that the optimal solution will fall inside the boundary. The following steps are used to set lower bound and upper bounds on all six decision variables (i.e., *DLS*, *Optss*, $OptS_r$, $ACB_r$ $EQ_r$ and $DS_r$ where $r = 1,2\ldots,N$)

*Discrete Lot Sizing (DLS)*

- Lower bound of Discrete Lot Sizing (*DLS*) is 1 or making an order in every period.
- Upper bound of Discrete Lot Sizing (*DLS*) is equal to the number of discrete lot sizing patterns, which is equal to $2^{T-1}$. Since the planning horizon (*T*) is equal to 6, the upper bound of *DLS* is equal to $2^{6-1}= 32$.

*Safety Stock Level (Optss)*

- Lower bound of the safety stock level at the manufacturer (*Optss*) is set at 0 or no inventory is kept at the manufacturer.
- During preliminary experiments, the safety stock level that was generated from GA has never exceeded 50% of the average demand in each period, the upper bound of the safety stock level at the manufacturer (*Optss*) is then limited to holding no more than 50% from the average demand in each period, which is equal to 1,125 units.

*Target stock level ($OptS_r$)*

- Lower bound of the target stock level at retailer *r* ($OptS_r$) should be at least equal to the expected demand during the review period plus the delivery lead time contract from the manufacturer.
  Lower bound of $OptS_1$ = 100 × (10+2) = 1,200 units
  Lower bound of $OptS_2$ = 50 × (10+2) = 600 units
  Lower bound of $OptS_3$ = 75 × (10+2) = 900 units

- Upper bound of the target stock level at each retailer ($OptS_r$) under the traditionally coordinating policy without an incentive scheme is set to achieve 99.85% service level, which should be high enough to cover the optimal solution. The equation can be shown as: $\overline{D_r} \times (Tp + LTC\_mr) + z\sqrt{(\overline{lt\_mr} \times \sigma^2_{D_r}) + (\overline{D_r}^2 \times \sigma^2_{lt\_mr})}$
  (see Tersine (1996) for further information)

where $\overline{D}_r$ and $\sigma_{D_r}$ are the mean and standard deviation for the end customer demand occurring at each retailer, ($r$ = 1,2... $N$), $\overline{lt\_mr}$ and $\sigma_{lt\_mr}$ are the mean and standard deviation of the delivery lead-time of finished products from the manufacturer to the retailers. Therefore, the upper bound of the target stock level at the retailers can be calculated as follows:

The upper bound of $OptS_1$

$$= 100(10+2)+3\sqrt{(2\times 25^2)+(100^2\times 1^2)} = 1{,}518 \text{ units}$$

The upper bound of $OptS_2$

$$= 50(10+2)+3\sqrt{(2\times 12^2)+(50^2\times 1^2)} = 758 \text{ units}$$

The upper bound of $OptS_3$

$$= 75(10+2)+3\sqrt{(2\times 15^2)+(75^2\times 1^2)} = 1{,}134 \text{ units}$$

However, when the manufacturer offers the quantity discount to each retailer, it appears that the retailers are willing to take such an advantage by purchasing more products. This results in the upper bound of the target stock level at each retailer ($OptS_r$) under the coordinating policy with an incentive scheme being set at 40% higher than the upper bound of the centralized controlling policy, which are equal to 2,125 units, 1,061 units and 1,588 units at retailer 1, 2 and 3 respectively.

*Accept or Reject the bonus ($ACB_r$)*

- A decision to accept or reject a bonus ($ACB_r$) is represented by a binary number (0 and 1). One means accepting the bonus while zero means rejecting the bonus. As a result, this decision variable requires only one bit in each chromosome.

*Percentage of Quantity Discount ($EQ_r$)*

- The lower bound of the percentage of exceeding units' quantity discount ($EQ_r$) is set at 0% or does not offer any discount.
- The upper bound of the percentage of exceeding units' quantity discount ($EQ_r$) is limited at a 20% discount from a unit purchasing cost for each unit purchased beyond the predetermined quantity discount level.

*Distribution Strategy of finished product ($DS_r$)*

- The lower bound of the percentage of distributing the amount of products on hand at the manufacturer to each retailer ($DS_r$) is set at 0% or does not supply any products to that retailer.
- The upper bound for the percentage of distribution of the amount of products on hand at the manufacturer to each retailer ($DS_r$) is set at 100% (supplies all products to only that retailer).

### 5.6.2 Second Step: Chromosome Structure and Coding

Binary coding is selected to represent the solution for this problem. Therefore, all parameters should be converted to binary strings.

Under the centralized controlling policy with both manufacturer domination and the entire chain's perspectives, the combined multi-parameter chromosome has the following form: $<DLS><Optss><OptS_1><OptS_2><OptS_3><DS_1><DS_2>$. Under the coordinating controlling policy with an incentive scheme, the chromosome has the following form: $<DLS><Optss><OptS_1><OptS_2><OptS_3><DS_1><DS_2><ACB_1><ACB_2>$ $<ACB_3><EQ_1><EQ_2><EQ_3>$. The length of the chromosome can be calculated as follows:

For *DLS*: $2^4 <(32\text{-}1)<= 2^5\text{-}1$, so the required bit for *DLS* = 5.
For *Optss*: $2^{10} < (1{,}125\text{-}0) <= 2^{11}\text{-}1$, so the required bit for *Optss* = 11.
For $OptS_1$: $2^8< (1{,}518\text{-}1{,}200) <= 2^9\text{-}1$, so the required bit for $OptS_1 = 9$.
For $OptS_2$: $2^7 < (758\text{-}600) <= 2^8\text{-}1$, so the required bit for $OptS_2 = 8$.
For $OptS_3$: $2^7 < (1{,}134\text{-}900) <= 2^8\text{-}1$, so the required bit for $OptS_3= 8$.
For $DS_r$: $2^{13} < (10000\text{-}0) <= 2^{14}\text{-}1$, so the required bit for $DS_r = 14$. (For $r = 1, 2$)
For $ACB_r$: $2^0 < (1\text{-}0) <= 2^1\text{-}1$, so the required bit for $ACB_r = 1$. (For $r = 1, 2, 3$)
For *EQr*: $2^4 < (20\text{-}0) <= 2^5\text{-}1$, so the required bit for $EQr = 5$. (For $r = 1, 2, 3$)

Therefore, the length of the chromosomes in the traditionally centralized controlling policies under the manufacturer domination and the entire chain's perspective are equal to 69 bits and the length of the chromosome in the coordinating controlling policy with an incentive scheme is equal to 87 bits.

### 5.6.3 Third step: Initializing Population

Genetic Algorithm starts with an initial set random solution called population. The population is set to contain 10 chromosomes. A random number generator is used to generate the initial population $P(k=0)$ in forms of binary numbers, where $k$ is a generation index.

### 5.6.4 Fourth step: Evaluation

Each chromosome in the population represents a potential solution to the problem. The evaluation function is responsible for rating these potential solutions by substituting a real number back to the objective function as a measure of its fitness. This is carried out in two steps as follows:

*Step 1: Mapping Binary Number to Real Number*

This step starts from convert the binary string from base 2 to base 10, and then finds the corresponding real number by using the equation 2 and 3 in Chapter 3.

*Step 2: Setting the Evaluation Function*

Due to the fact that this problem is a constraint optimization, the penalty function is selected to handle all the constraints. Penalty strategy transforms the constrained problem into an unconstrained problem by penalizing infeasible solutions, in which a penalty term is added to the objective function for any violation of the constraints. Under a centralized controlling policy with the manufacturer domination, the solution will be penalized when the fill rate of the manufacturer is less than the required service level ($\beta$). However, under the centralized controlling policy with the entire chain's perspective and coordinating controlling policies, the solutions will be penalized when the fill rate at any retailers is less than the required service level ($\beta$).

The evaluation function ($Eval_t$) of the centralized controlling policy under the manufacturer domination is presented as follows:

$$Eval_t = \Pi m - \begin{cases} 0 & \text{if } FRm_{rt} > \beta \\ (\beta - FRm_{rt}) \times D_{rt} \times k & \text{otherwise} \end{cases} \tag{56}$$

The evaluation function ($Eval_t$) of the centralized controlling policy under the entire chain's perspective is presented as follows:

$$Eval_t = \Pi s - \begin{cases} 0 & \text{if } FR_{rt} > \beta \\ (\beta - FR_{rt}) \times D_{rt} \times k & \text{otherwise} \end{cases} \tag{57}$$

The evaluation function ($Eval_t$) of the coordinating controlling policy with an incentive scheme is presented as follows:

$$Eval_t = \Pi joint - \begin{cases} 0 & \text{if } FR_{rt} > \beta \\ (\beta - FR_{rt}) \times D_{rt} \times k & \text{otherwise} \end{cases} \tag{58}$$

where $k$ is the generation index for $k = 1$ to $k_{max}$

Note that the measures of infeasibility from equation 56 to 58 are multiplied by the number of generations, so as to increase the pressure on infeasible individuals.

### 5.6.5 Fifth Step: Selection and Genetic Algorithm's Operators

The roulette wheel approach is chosen as the method to select the chromosomes and create a mating pool for their reproduction. The roulette wheel approach belongs to the fitness-proportion selection and can select a new population with respect to the probability distribution based on fitness values.

Having selected the operation, a mating pool is formed. The next step is to do a crossover operation. The crossover operation used in the study is a random one cut-point, which exchanges the right parts of two parents to generate an offspring. Then, the mutation operator flips a bit in a chromosome by a random method. After the first generation has been completed, the new population will be collected. Then, the process repeats itself until 10,000 generations.

## 5.7 Results of the Numerical Example of the Single Manufacturer and Multi-Retailers' Supply Chain

The results are divided into 3 sections according to each comparative perspective. Table 5.3 presents the profit and the fill rate from each member in the chain as well as the total chain's profit. The numbers shown in the table are the average value from 10 replications over 6 periods (60 days) per replication. In addition, Table 5.4 reveals the best settings for each decision variable as generated by the Genetic Algorithm. Lastly Table 5.5 presents the relevant costs of each member in the chain.

Table 5.3 Comparison of the performances among different perspectives (6 periods' planning horizon)

| Performance of the supply chain system | Centralized control | | Coordinating Control with EUQD&Bonus |
|---|---|---|---|
| | Manufacturer domination | Entire chain's perspective | |
| Profit of the chain ($) | 2,116,093 | 2,260,493 | 2,545,266 |
| Profit of the manufacturer ($) | 1,362,762 | 1,306,282 | 1,556,933 |
| Profit of retailer 1 ($) | 382,312 | 467,527 | 477,122 |
| Profit of retailer 2 ($) | 121,026 | 153,602 | 155,210 |
| Profit of retailer 3 ($) | 249,994 | 343,082 | 356,002 |
| Fill rate of the manufacturer that supplies parts to retailer 1 (%) | 100.00 | 85.67 | 90.97 |
| Fill rate of the manufacturer that supplies parts to retailer 2 (%) | 100.00 | 82.68 | 90.04 |
| Fill rate of the manufacturer that supplies parts to retailer 3 (%) | 90.06 | 96.39 | 95.14 |
| Fill rate of retailer 1 (%) | 99.83 | 98.05 | 99.71 |
| Fill rate of retailer 2 (%) | 99.47 | 95.27 | 98.93 |
| Fill rate of retailer 3 (%) | 90.12 | 99.50 | 99.94 |

### 5.7.1 Centralized Controlling Policy under Manufacturer Domination

In this instance, the manufacturer tries to optimize its own profit by increasing its revenue and reducing its costs. As shown in Table 5.4, the operations have forced retailers 1 and 2 to set relatively high levels of their target stock at 1,430 units and 714 units respectively. At the same time the manufacturer has also decided to hold more stock (highest safety stock level relative to all perspectives) and to supply more products to retailers 1 and 2 (as shown by 100% fill rate for both retailers) but only to supply a 90.95% fill rate to retailer 3. This is due to the fact that the profit margin of selling one unit of the product to retailer 1 ($\approx$ 20.06%) and retailer 2 ($\approx$ 19.08%) are higher than the profit margin per unit of selling to retailer 3 ($\approx$ 18.11%). Moreover, retailerl and r etailer 2 have also charged the manufacturer a higher shortage cost. Having done that, the manufacturer can increase its revenue and avoid paying a high shortage cost when only looking at its own perspective.

As its objective, even though all members gain profit, the manufacturer gains the highest profit when there exist some level of unfair treatment to some retailers in the chain, especially in the case of retailer 3, who seems to have the lowest bargaining power and as a result, has been given lower priority in supplied parts from the manufacturer.

Even though the manufacturer aims to maximize its own profit, it has never appeared that the manufacturer solely sells the products to only one or a few retailers who may yield the highest profit to the manufacturer and ignores the orders from others. This is due to the fact that the manufacturer has to pay the shortage cost for any unfulfilled retailer's demand since they are operating in the same supply chain. Therefore, this constraint forces the manufacturer not be able to reject the orders from all retailers. However, if the shortage cost is removed from the profit function, the manufacturer may then ignore the orders from some retailers who yield the lower profit.

Table 5.4 Comparison of decision variables among different perspectives (6 periods' planning horizon)

| Decision Variables | Centralized control | | Coordinating control with EUQD&Bonus |
|---|---|---|---|
| | Manufacturer domination | Entire chain's perspective | |
| *DLS* (ordering policy) | (1, 2)(3,4)(5,6) 7 from 10 replications | (1,2)(3)(4)(5)(6) 7 from 10 replications | (1,2)(3)(4)(5)(6) 7 from 10 replications |
| *Safety stock level at the manufacturer* (units) | 579 | 106 | 469 |
| *Target stock level at retailer 1* (units) | 1,430 | 1,403 | 1,528 |
| *Target stock level at retailer 2* (units) | 714 | 671 | 770 |
| *Target stock level at retailer 3* (units) | 1,000 | 1,065 | 1,197 |
| *Accept or reject bonus offered from retailer 1* | - | - | Accept 3 from 10 replications |
| *Accept or reject bonus offered from retailer 2* | - | - | Accept 4 from 10 replications |
| *Accept or reject bonus offered from retailer 3* | - | - | Accept 8 from 10 replications |
| *Percent discount offered to retailer 1* (%) | - | - | 3 |
| *Percent discount offered to retailer 2* (%) | - | - | 3 |
| *Percent discount offered to retailer 3* (%) | - | - | 2 |
| *Percentage of parts distributed to retailer 1* (%) | 45.41 | 40.81 | 42.88 |
| *Percentage of parts distributed to retailer 2* (%) | 29.52 | 23.04 | 24.46 |
| *Percentage of parts distributed to retailer 3* (%) | 25.07 | 36.15 | 32.66 |

### 5.7.2 Centralized Controlling Policy under the Entire Chain's Perspective

This policy is intended to optimize the profit of the whole chain, rather than optimizing the sole profit of one particular member. The results from Table 5.3 show that the profit of the entire chain has increased by 5.93% from the manufacturer domination case. As expected, the profit of the manufacturer has reduced while the profit of the retailers has increased. Due to the entire chain's perspective, rather than solely looking at the manufacturer's benefit, each member operates by aiming at the common benefit of the entire chain. As a result, the manufacturer tends to supply more products to retailer 3, as retailer 3 is the main profit contributor to the chain, and sells the product with the highest profit margin to the end customers (≈ 11.91%). On the other hand, the profit margin at retailer 1 and retailer 2 to their customers are only set at approximately 9.5% and 7.96% respectively. By setting a high target stock level for retailer 3 (1,065 units as show in Table 5.4), retailer 3 can supply more products to the end customers.

This has been shown by the fill rate from the manufacturer to retailer 3, which is as high as 96.39% (others are dropped to around 82-86%) and the fill rate from retailer 3 to the end customers, which is at the highest with 99.50% (retailer 1 is at 98.05% and retailer 2 is only at 95.27%).

### 5.7.3 Coordinating Controlling Policy with an Incentive Scheme (EUQD&Bonus)

It can be seen, from Table 5.3 as well as Figure 5.2 that by implementing an incentive scheme between the manufacturer and all retailers, the profit of the entire chain is at the highest when compared to the profits obtained from all comparative perspectives. In addition, individual profits from all members in the chain are also at their highest. By giving the discount at the rate of 2% to retailer 3 and 3% to retailers 1 and 2, all retailers have shown to take an advantage of buying at a discounted price (also leading to a reduction in their holding cost per unit) and set a higher target stock level. As a result, each retailer spends higher holding cost for more stock holding. However, this not only increases the ability of the retailers to supply more end customer's demand but also brings higher revenues and saves the shortage cost at the retailers as illustrated in Table 5.5.

In order to get a bonus from each retailer, the manufacturer has to achieve two requirements (both on time delivery and correct amount). The manufacturer can speed up its delivery by paying the activated cost and prevents any shortage by holding and producing sufficient amount of stock. The objective of this controlling policy is to optimize the profit of the chain (not individual). The results from GA suggest the manufacturer does not accept all retailers' bonus simultaneously. This is to avoid holding too much safety stock and incurring too high holding cost. Due to the fact that only a 2% discount is given to retailer 3 and that the highest profit margin can be made from this retailer, the manufacturer normally accepts the bonus from retailer 3 (accepting 8 from 10 replications), but rarely accepts the bonus from retailer 1 and retailer 2 (accepting 3 and 4 from 10 replications, respectively).

Table 5.5 Comparison of cost parameters among different perspectives (6 periods' planning horizon)

| Cost parameter | Centralized control | | Coordinating Control with EUQD&Bonus |
|---|---|---|---|
| | Manufacturer domination | Entire chain's Perspective | |
| Holding cost of raw materials at the manufacturer ($) | 10,185 | 6,342 | 8,860 |
| Holding cost of products at the manufacturer ($) | 40,938 | 35,026 | 34,423 |
| Shortage cost of the manufacturer give to retailer 1 ($) | 0 | 12,562 | 9,050 |
| Shortage cost of the manufacturer give to retailer 2 ($) | 0 | 8,169 | 6,133 |
| Shortage cost of the manufacturer give to retailer 3 ($) | 10,984 | 2,025 | 1,989 |
| Holding cost of product at retailer 1 ($) | 50,393 | 44,655 | 46,007 |
| Holding cost of product at retailer 2 ($) | 29,959 | 24,778 | 25,072 |
| Holding cost of product at retailer 3 ($) | 20,481 | 32,535 | 33,660 |
| Opportunity of shortage cost of retailer 1 ($) | 1,952 | 4,964 | 1,726 |
| Opportunity of shortage cost of retailer 2 ($) | 1,090 | 5,085 | 2,096 |
| Opportunity of shortage cost of retailer 3 ($) | 10,611 | 2,150 | 1,056 |

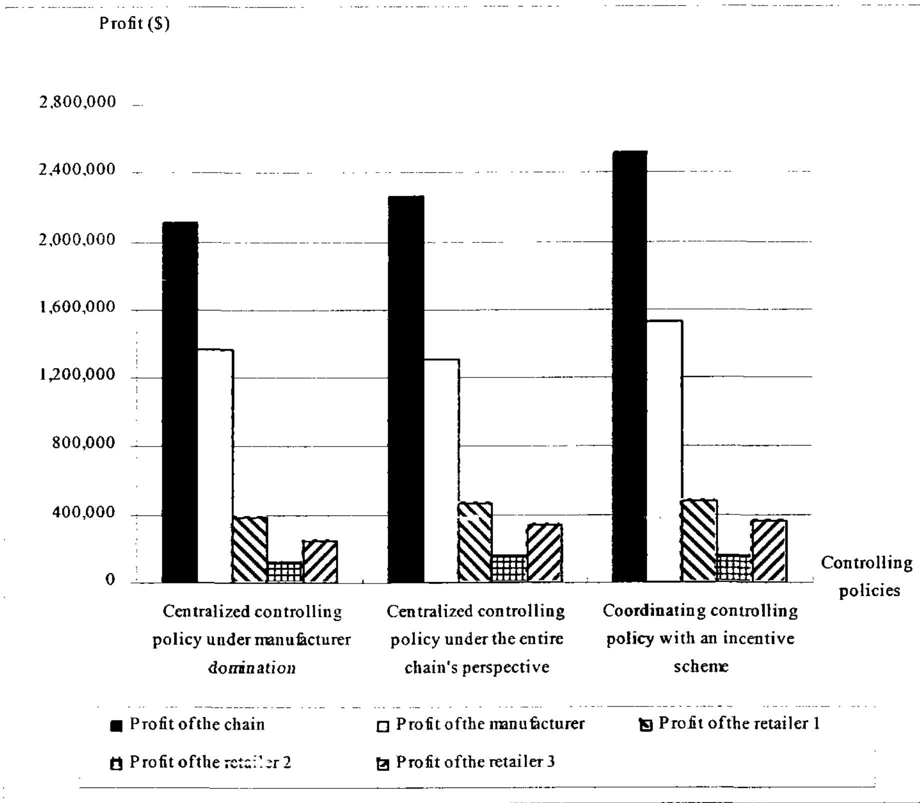


Figure 5.2 Comparison of the profit under the different controlling policies.

## 5.8 Sensitivity Analysis from Varying the Bonus in the Single Manufacturer and Multi-Retailers' Supply Chain

To investigate the effect of varying the bonus on the profits, the profit of the chain and the profits of each retailer under the centralized controlling policy with the entire chain's perspective are used to be the profit base line for comparison while the profit of the manufacturer under the manufacturer domination is considered to be the base line profit to compare with the profit of the manufacturer. This is to check whether when the incentives have been exchanged, a win-win situation for all members can still be achieved. Normal case is representing the profit under coordinating controlling policy without varying bonus value. Table 5.6 shows the results of the sensitivity analysis.

We have carried out the sensitivity analysis by varying the bonus (±10% and ±20%) in this single manufacturer and multi-retailers' supply chain. When the bonus is reduced, the manufacturer's profit reduces while the retailers' profit increase and vice versa (comparing to the profit from the normal case). However, the retailers seem to have more effect from increasing the bonus than the manufacturer, particularly when the bonus is increased, as shown in Figure 5.3 to 5.7. When the bonus is high, each retailer has to reduce its target stock level to save some expenses. This leads to a reduction in sales volume at each retailer and also at the manufacturer. Since the system aims to maximize the profit of the chain, there is less of a chance that the bonus will be accepted. When the bonus is rejected, each retailer needs to hold high stock level to protect itself against the shortage also it has already gained the benefit from the discount. Therefore, the manufacturer profit is more stable under bonus variation.

However, it is obviously seen from Figure 5.3 to 5.7that the chain and all members can still maintain their profits beyond the profit base lines. It implies that under up to 20% bonus variation, the coordinating controlling policy can still achieve a win/win situation.

Table 5.6 Comparison of the performances of the chain and all members under bonus variations of a single manufacturer and multi-retailers' supply chain

| Performance of the supply chain | Profit base line | Sensitivity analysis of the bonus | | | | |
|---|---|---|---|---|---|---|
| | | -20% | -10% | Normal case | 10% | 20% |
| Profit of the chain ($) | 2,260,493 | 2,481,936 | 2,509,919 | 2,514,266 | 2,504,299 | 2,491,144 |
| Profit of the manufacturer ($) | 1,362,762 | 1,490,636 | 1,512,193 | 1,525,933 | 1,526,140 | 1,523,772 |
| Profit of retailer 1 ($) | 467,527 | 477,386 | 480,269 | 477,122 | 472,996 | 468,546 |
| Profit of retailer 2 ($) | 153,602 | 157,166 | 157,869 | 155,210 | 154,256 | 154,255 |
| Profit of retailer 3 ($) | 343,082 | 356,748 | 359,588 | 356,002 | 350,907 | 344,572 |

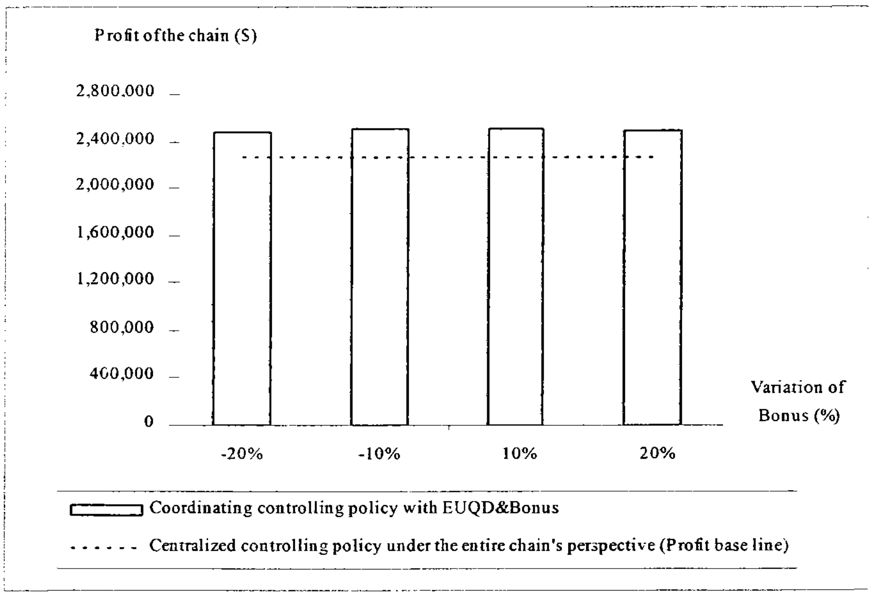


Figure 5.3 Effect of the bonus variation on the performance of the chain in the single manufacturer and multi-retailers' supply chain.

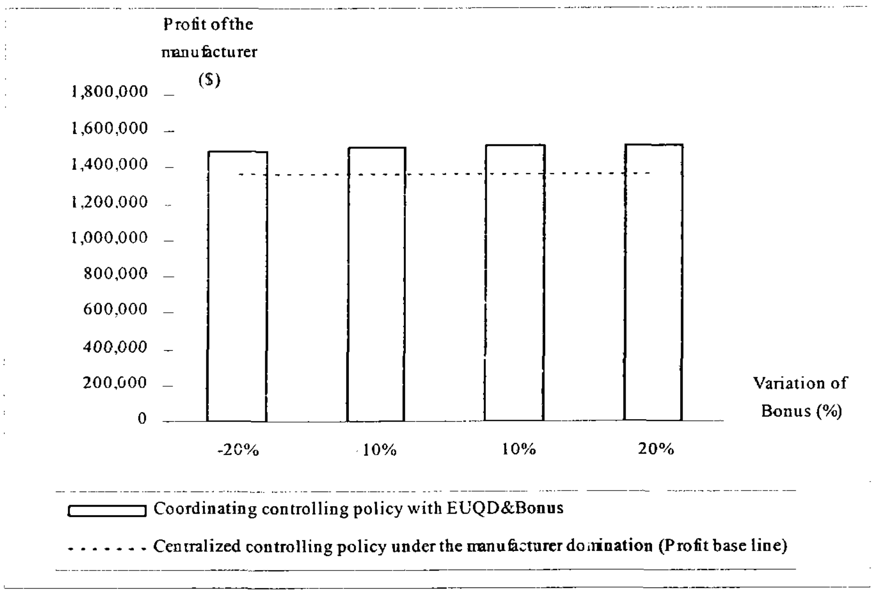


Figure 5.4 Effect of the bonus variation on the performance of the manufacturer in the single manufacturer and multi-retailers' supply chain.

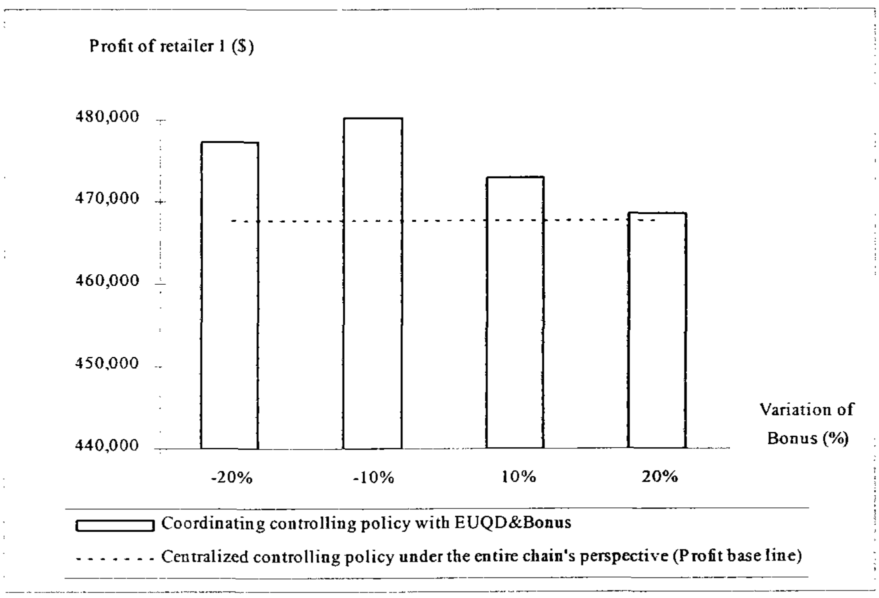


Figure 5.5 Effect of the bonus variation on the performance of retailer 1 in the single manufacturer and multi-retailers' supply chain.

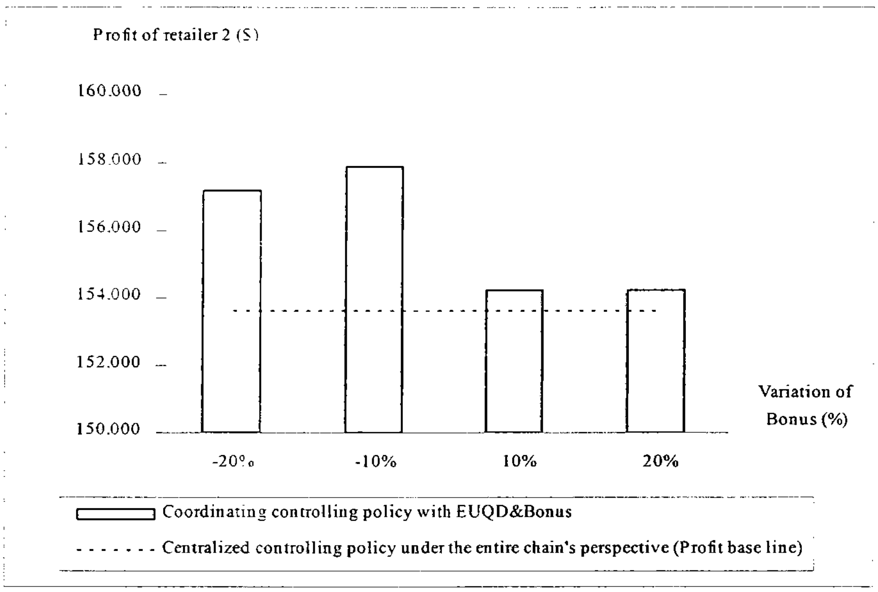


Figure 5.6 Effect of the bonus variation on the performance of retailer 2 in the single manufacturer and multi-retailers' supply chain.

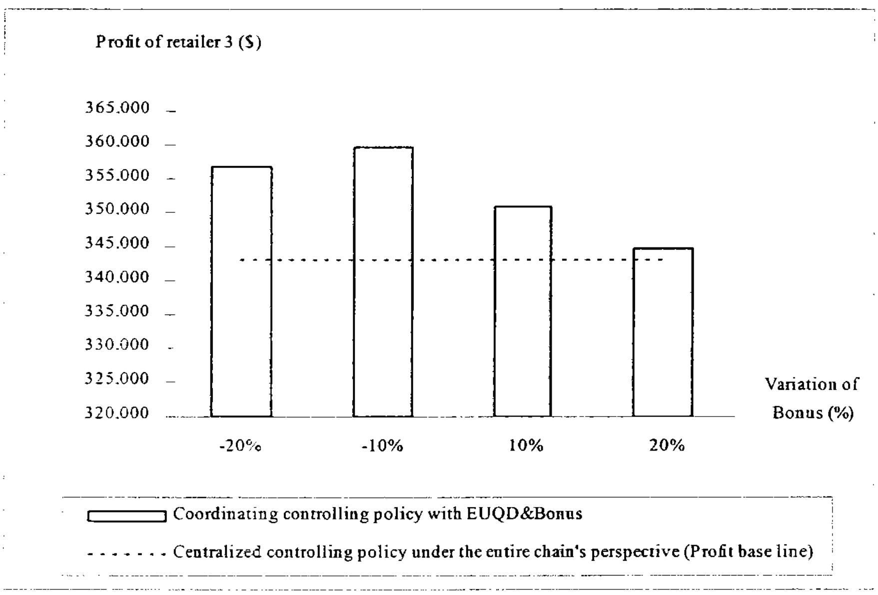


Figure 5.7 Effect of the bonus variation on the performance of retailer 3 in the single manufacturer and multi-retailers' supply chain.