# CHAPTER 3

## METHOD OF APPROACH

This chapter discusses the framework of the study. The study is aimed to analyze the relationship in a supply chain. However, there are several types of the chain's configuration such as a single chain with a dyadic relationship to a network chain with multiple buyers or sellers. Each configuration may require different policies in managing their chains and may yield different outcomes. These will be discussed in the following chapters.

Although overall performance of the supply chain depends on the companies' joint performance, the optimal goals may conflict and result in an inefficiency for the entire chain. Therefore, one of the main issues of this study is to find suitable mechanisms for coordinating the logistical processes that are controlled by various independent companies in order to achieve an overall minimum cost and maximum profit. To achieve these goals, the framework as presented in Figure 3.1 is constructed and each step in our framework can be shown as follows:

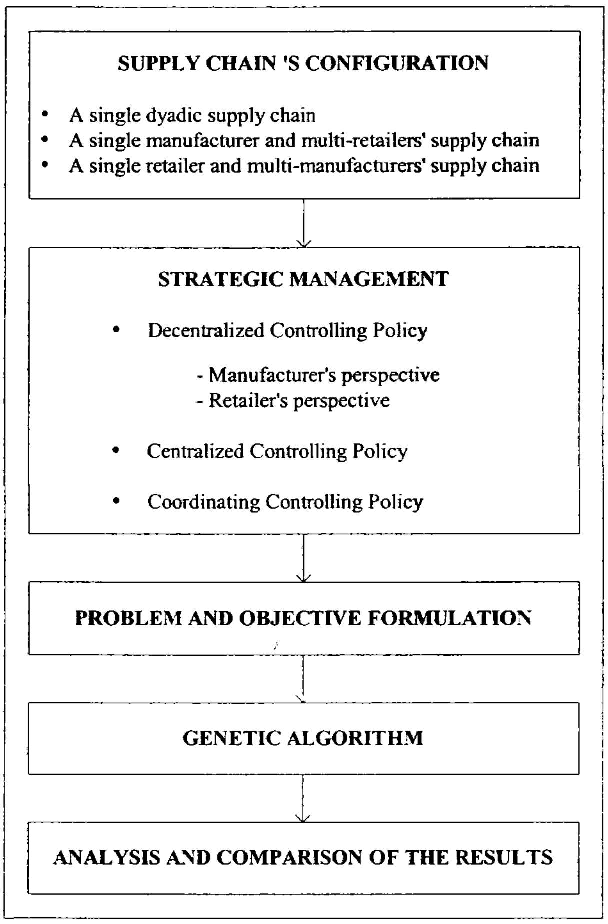


Figure 3.1: Basic methodology

## 3.1 Supply Chain's Configuration

General structures of our supply chain consist of four echelons which are the supplier, the manufacturer, the retailer and end customers. However, this study mainly focuses only at a relationship formed between the manufacturer and the retailer. In practice, there could be one or more members at each echelon. Three configurations of the chain consisting of "a single dyadic chain", "a single manufacturer and multi-retailers' chain" and "a single retailer and multi-manufacturers' chain" are in the scope of the study.

### 3.1.1 A Single Dyadic Supply Chain

This is a basic supply chain system which considers the relationship formed between two single parties which are a manufacturer and a retailer (Discussed in Chapter 4). An example of real world instance for this situation is the case of a small chain formed between single manufacturer and single retailer where the manufacturer probably has its own retail store. The configuration of this supply chain is illustrated in Figure 3.2.

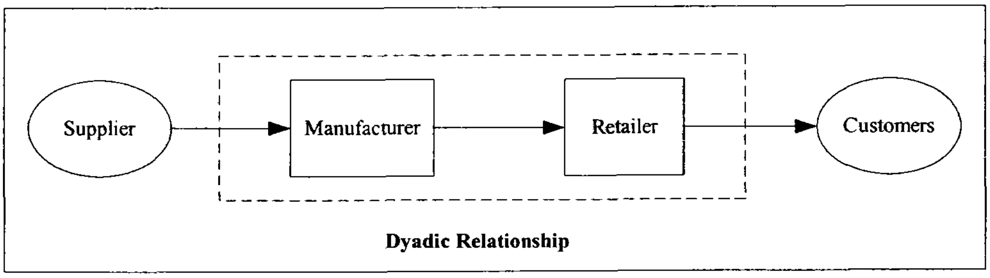


Figure 3.2 Configuration of a single dyadic supply chain.

### 3.1.2 A Single Manufacturer and Multi-Retailers' Supply Chain

When a chain is dominated by a manufacturer or when several retailers need to rely on one manufacturer's product, the manufacturer can sell its product to multiple retailers. If the amount of product on hand of the manufacturer is less than the aggregate demand from all retailers, the manufacturer must make a distributing decision to spread out a portion of available units to certain retailers. So a single manufacturer and multi-retailers supply chain is built to demonstrate this situation (Discussed in Chapter 5). An example of real world instances for this situation is the case of automotive industries where a manufacturer needs to distribute its product to more than one authorized dealers. The configuration of this supply chain is illustrated in Figure 3.3.

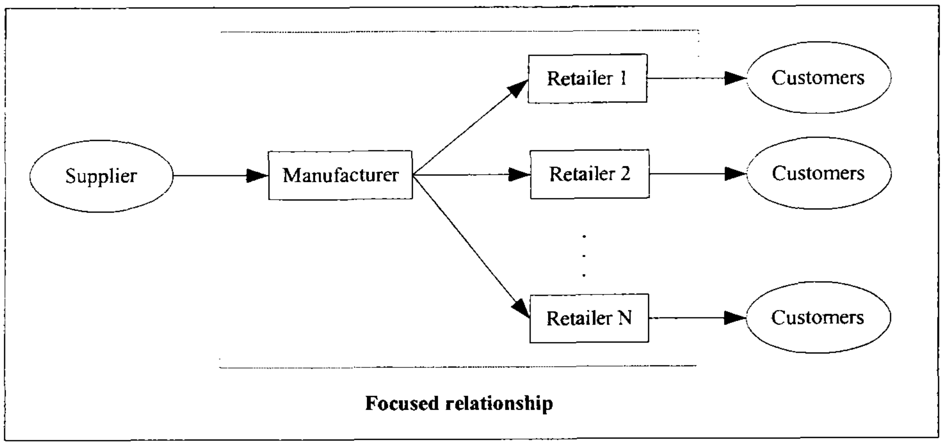


Figure 3.3 Configuration of a single manufacturer and multi-retailers' supply chain

### 3.1.3 A single Retailer and Multi-Manufacturers' Supply chain

When a chain is dominated by a retailer or a situation when a retailer can place its order to several manufacturers who produce the same product, the retailer needs to judge and share the right amount of orders to each manufacturer. This may reduce fear of the dependency on a single supplier. Therefore, a single retailer and multi-manufacturers' supply chain is built to demonstrate this situation (Discussed in Chapter 6). The real world instances of this situation are the big retailer chains (convenient stores and discount stores) such as Wal-Mart, Seven-Eleven and Tesco-Lotus where they purchases products from multiple manufacturers and supply to their customers. The configuration of this supply chain is illustrated in Figure 3.4.

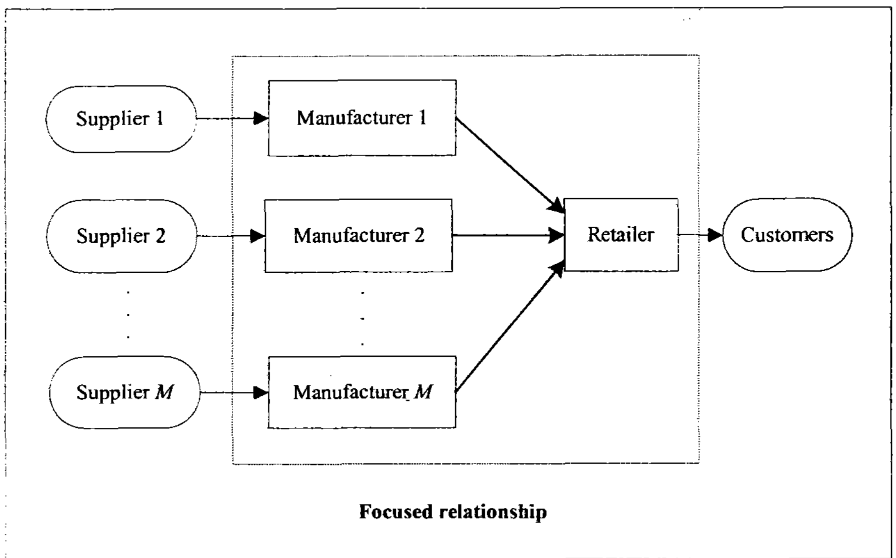


Figure 3.4 Configuration of a single retailer and multi-manufacturers' supply chain

## 3.2 Strategic Management in the Supply Chain

Different organizations implement different strategic managements to control the operation among members in the chain. The performance of our chains have been studied under three controlling policies which are the decentralized controlling policy, the centralized controlling policy and the coordinating controlling policy with an incentive scheme as illustrated in Table 3.1.

Table 3.1 Strategic management in each supply chain system

| Supply chain system | Decentralized controlling policy | Centralized controlling policy | Coordinating controlling policy |
|---|---|---|---|
| A single dyadic chain | - Manufacturer's perspective<br>- Retailer's perspective | - Entire chain's perspective | - One-sided incentive<br>- Two-sided incentive |
| A single and multi-retailers' chain | - | - Manufacturer domination<br>- Entire chain's perspective | - Two-sided incentive |
| A single retailer and multi-manufacturers' chain | - | - Retailer domination<br>- Entire chain's perspective | - Two-sided incentive |

Decentralized controlling policy is usually implemented when each member in the chain belongs to different organizations and each member acts as a single decision maker to optimize its own profits. The inventory level, ordering policy and production units of each member are controlled independently according to their own demand forecasting. Since there is no information sharing in the system, the forecasted demands at each level include some variations and causes error in setting the correct productive level. Two decentralized control models can be created according to different view points, which are manufacturer's perspective and retailer's perspective.

Centralized controlling policy views the system as one entity and there is one central planner who can make all decisions so as to maximize the profit of the whole system (entire chain's perspective). Under this situation, the full information sharing must be implemented and this results in minimum error of forecasting the demand at each level. It may be difficult to implement the centralized controlling policy, when all members in the chain are not belonging to the same owner. This is due to the fact that one member may gain more while the others earn less. Despite balancing and fairly sharing these benefits, the centralized and full cooperation in the chain are hardly materialized. In addition, with multi-manufacturers or multi-retailers' chain structures, the centralized controlling policies under the manufacturer and retailer dominations are also added to the comparison. This is to draw the base line profits of the manufacturer and retailer for justifying a win-win situation since these situations usually occur when the chain is dominated by the manufacturer or the retailer.

Coordinating controlling policy with an incentive scheme is designed to enhance the relationship formed between two independent members. In practice, such information sharing is hardly achieved without any incentive and full cooperation from their partners in the chain. Therefore, each member should contribute some forms of benefit (financial incentive in our case) to their partners as a means to link both partners and aims to improve even more the performance of the supply chain as well as their own companies. The coordinating policy with incentives also aims to maximize a joint profit between the manufacturer and the retailer while each member still has its authority to accept or reject the offered incentives from their partner as their joint profit is to be maximized.

### 3.3 Problem and Objective Formulation

Due to the complexity of our problem, simulation is employed for the analysis. All experimental models for the above systems are developed and coded by the Visual Basic for Application. We have performed a number of preliminary experiments in each model prior to actual runs for understanding their basic characteristics. This helps us to correctly set the appropriate cost structure and suitable range of our decision variables.

Due to the stochastic nature of the problem in this study, 10 replications in which each replication has a length of 6 periods (60 days) have been experimented with. This number of replications and its length have been analyzed to give sufficient data and allow the half width under 95% of confident intervals of the interested observation (the total profit of the chain) to be within 5% of its mean in all models.

#### 3.3.1 Constraint of the Models

Main constraints of this study are described as follows:

1. The manufacturer has a fix production rate. The production capacity of the manufacturer is the multiplication of the production rate and available production time. If the supplier delivers raw materials to the manufacturer on time, the available production time is equal to number of day in each period, otherwise the available production time is reduced.
2. Each member is allowed to make only one order in each period. If the manufacturer or the retailer has insufficient products on hand to supply the demand, they cannot make an extra order. So unfulfilled demand is considered to be shortage.
3. Safety stock at the manufacturer will be used only when the retailer's demand is greater than the quantity of products on hand, and it requires to fill back as soon as possible.
4. Even though this study aims to maximize the profit, customer satisfaction is also taken into consideration. Customer satisfaction refers to the proportion of demand satisfied at each selling point, which can also be called "fill rate" in this study. Therefore, the fill rate must be greater than or equal to the desired service level that is set at 90% in this study.

#### 3.3.2 Objective Function of Decentralized Controlling Policy under the Manufacturer's Perspective

Under the case of the decentralized controlling policy when each member in the chain aims to maximize its own profit, the objective function is then to maximize the profit of each member. Decentralized Controlling Policy under the Manufacturer's Perspective aims to maximize the profit of the manufacturer.

*Maximize profit of the manufacturer*

Profit of the manufacturer = Revenue of the manufacturer
− Total operating costs of the manufacturer

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

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

### 3.3.3 Objective Function of Decentralized Controlling Policy under the Retailer's Perspective

The objective function of this model is to maximize the profit of the retailer.

*Maximize profit of the retailer*

Profit of the retailer = Revenue of the retailer − Total operating cost of the retailer

Revenue of the retailer**
= (Sales price per unit of the retailer x Sales volume of the retailer)
+ (Unit shortage cost x Quantity of shortage of the manufacturer)

Total operating costs of the retailer = Holding cost of the finished product
+ Opportunity shortage cost
+ Ordering cost
+ Purchasing cost of the finished product
+ Administration cost

### 3.3.4 Objective Function of Centralized Controlling Policy

As mentioned in the previous section, the centralized controlling policy is aimed to maximize profit of the entire chain, not the profit from an individual member. Since our study focuses on the relationship formed between the retailer and the manufacturer, the profit of the chain consists of the profits from these two partners.

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* The manufacturer pays "*the penalty cost of shortage*" to the retailer for each unit that cannot fulfill the retailer's demand.

** Revenue of the retailer includes the revenue from selling the products to the end customers and the revenue from receiving the penalty cost of shortage paid by the manufacturer for each unit that cannot fulfill the retailer's order.

*Maximize total profit of the chain*

Total profit of the chain = Profit of the manufacturer + Profit of the retailer

### 3.3.5 Objective Function of Coordinating Controlling Policy with an incentive scheme

*Maximize Total joint profit of the chain*

Total joint profit of the chain = Profit of the manufacturer + Profit of the retailer

There are several types of incentive schemes. In this study, bonus, rebate and quantity discount are introduced as the coordinating mechanism to enhance the linkage of member in the chain. More details of this incentive scheme will be discussed in Chapter 4.

**With Bonus Incentive**

Profit of the manufacturer
= (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*

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

**With Rebate Incentive**

Profit of the manufacturer
= (Sales price per unit of the manufacturer x Sales volume of the manufacturer)
- Holding cost of raw material - Holding cost of finished product
- Penalty cost - Ordering cost - Purchasing cost of raw material
- Production cost - *Rebate paid to the retailer*

Profit of the retailer
= (Sales price per unit of the retailer x Sales volume of the retailer)
+ Penalty cost paid by the manufacturer
+ *Rebate given by the manufacturer*
- Holding cost of the finished product - Opportunity shortage cost
- Ordering cost - Purchasing cost of the finished product
- Administration cost

**With Quantity Discount Incentive**

Profits of the manufacturer and the retailer have the same cost structure as the centralized controlling policy without an incentive. However, if the retailer purchases the products beyond the pre-determined level, the retailer will get the discount. As a consequence, purchasing cost of the finished product at the retailer is reduced.

Definition and significance of incentive cost parameters such as activated cost, bonus, discount and rebate will be discussed in Chapter 4.

### 3.4 Genetic Algorithm (GA)

Genetic algorithm is an optimization algorithm which is based on the mechanism of natural genetic and natural selection and has a property of stochastic searches. The beginning of genetic algorithms is credited to John Holland, who developed the basic idea in the late 1960s and developed it in early 1970s (Chong, and Zak, 1996). Genetic algorithms have been widely used as a tool in computer programming and artificial intelligence, optimization, neural network training, and in many other areas. GA can apply to solve combinatorial optimization, engineering control, engineering design, and planning and scheduling.

Unlike conventional searching techniques, Genetic Algorithm (GA) starts with an initial set of random solutions called population. Each individual in the population is called a chromosome, and represents a solution to the problem at hand. A chromosome is a string of symbols and is usually, but not necessarily, a binary bit string. The chromosomes evolve through successive iterations, called generations. During each generation the chromosomes are evaluated which corresponds to a value of the objective function, referred to as the fitness of the chromosome. Then the selection operation is applied to form a mating pool, the chromosomes are selected into a mating pool with probabilities proportional to their fitness value, so that fitter chromosomes have a higher probability of being selected. Unselected chromosomes are rejected so as to keep the population size constant.

To create the next generation, new chromosomes are formed by either using a crossover operator or a mutation operator. This operation is called evolution. The crossover operation takes a pair of chromosomes, called the parents and gives a pair of new chromosomes, called offspring. The operation involves exchanging sub-strings of the two parent chromosomes. After the crossover operation, the parents are replaced in the mating pool by their offspring. The mating pool has therefore been modified, but still maintains the same number of elements. Then, a mutation operation is performed. This operation takes each chromosome from the mating pool and randomly changes each symbol of the chromosome according to a given probability. In the case of a binary code, this changes codes from 0 to 1, or vice versa. A new population is formed, and then repeated in the procedure of evaluation, selection and evolution iteratively (Deb, 1995, Chong and Zak, 1996, Gen and Cheng, 1997).

The stopping criterion can be implemented in a number of ways. Our stopping criterion is to stop when the performance of chromosome does not change from iteration to iteration.

#### 3.4.4 Solving the Problem by Genetic Algorithm

GA is inspired by the process of natural evolution and the principle of survival of the fitness. GA iteratively generates new solutions from currently available solutions and replaces some portion of the existing members of the current solutions with the newly created members. The algorithm of the GA can be summarized in Figure 3.5.

#### 3.4.1.1 First step: Setting Lower Bound and Upper Bound of the Solution

The lower and upper bound of each decision variable is set to limit the computational time from GA. However, the searching boundary for each decision variable must be large enough to ensure that the optimal solution will fall inside the boundary.

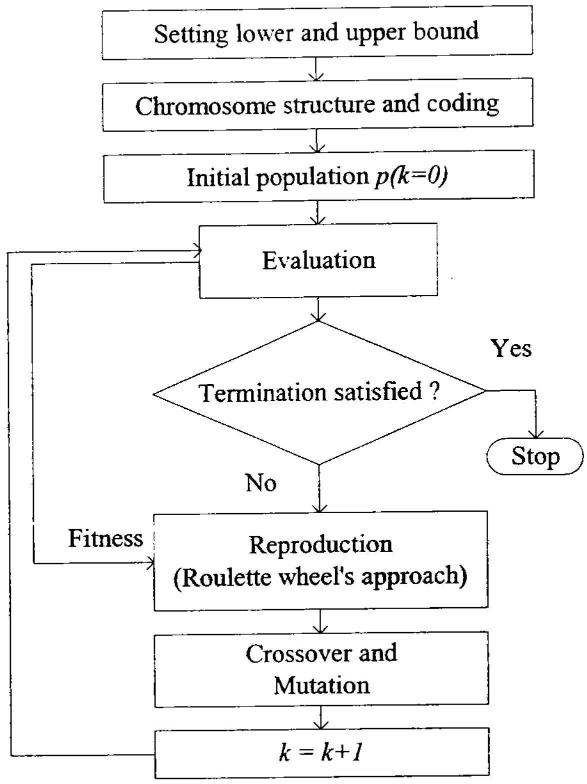


Figure 3.5: Genetic Algorithm's Procedures

#### 3.4.1.2 Second step: Chromosome Structure and Coding

The binary coding is selected to represent the solution for this problem. Therefore, all parameters should be converted into binary strings. The required bits (denoted with $m_i$) for each decision variable are calculated as follows:

$$2^{m_i - 1} < (u_i - l_i) \leq 2^{m_i} - 1 \qquad (1)$$

where $i$ is a decision variables index.
$l_i$ is lower bound of decision variable $i$
$u_i$ is upper bound of decision variable $i$

#### 3.4.1.3 Third step: Initializing Population

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

3.4.1.4 Fourth step: Evaluation

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

*Step 1: Mapping binary number to real number*

- Convert the binary string from base 2 to base 10

$$\left(\left\langle b_{m_i-1} b_{m_i-2} \ldots b_0 \right\rangle\right)_2 = \left( \sum_{a=0}^{m_i-1} b_a 2^a \right) = decimal(chromosome_i) \quad (2)$$

where $a$ is the position of each bit and $b_{m_i}$ is the binary coding of chromosomes $i$.

- Find a corresponding real number ($x_i$)

$$x_i = l_i + \left( decimal(chromosome_i) \cdot \frac{u_i - l_i}{2^{m_i} - 1} \right) \quad (3)$$

*Step 2: Setting the evaluation function*

Due to the fact that the problem in this study is a constraint optimization, the penalty function is selected to handle all constraints. Penalty strategy transforms the constrained problem into an unconstrained problem by penalizing ($penalty_s$) infeasible solutions, in which a penalty term is added to the objective function for any violation of the constraints. The evaluation function ($Eval_s$) is presented as follows:

$$Eval_s = profit_s + penalty_s \quad (4)$$

where $s$ is a chromosome index.

3.4.1.5 Fifth step: Selection and Genetic Operators

The roulette wheel approach is chosen as the method to select the chromosome and makes a mating pool for 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 using the random method. After the first generation has completed, the new population size will be collected. Then, the process repeats itself until the generation reaches the stopping criterion or is terminated ($k_{max}$).

### 3.4.5 Why Genetic Algorithm?

Due to the complexity of the studied models, which include a number of if-else conditions (see the details in chapter 4, 5 and 6), the problem in this study is considered as NP-hard, which is renowned for its difficulty in solving, particularly if optimal solutions are required. The two principal methods used to solve NP-hard problems are based on the enumeration method and artificial intelligence (AI). The enumeration method guarantees optimal solutions, but is difficult to use in some applications due to the fact that their performance does not scale well on larger problems. As a consequence, it has been enhanced with the addition of heuristics. Among various AI methods, the Genetic Algorithm (GA) has been widely used in recent years by many researchers to overcome the drawbacks of mathematical models (Chan and Hu, 2001). Therefore, GA is selected to solve the problems in this study.

### 3.4.6 Validation of Results Obtained from Genetic Algorithm

The performance of GA is also validated for its optimality by comparing its solutions with the optimal solution from the enumeration method. However, it is impossible to generate the result of the enumeration method for the problem of our size (i.e. it requires 509,120,000 computational patterns from all interested decision variables in a single dyadic supply chain under the centralized controlling policy), in which the computational load and time would be beyond the feasible range of ability of normal personnel computers (i.e., using Pentium 4 processor, CPU 2.4 GHz, 256 MB RAM).

In order to get the optimal solution from the enumeration method as a benchmark for comparison purposes, a simplified model of the centralized controlling policy under single dyadic supply chain is developed by reducing its planning horizon to 4 periods and setting the demand at 20 units per day with a standard deviation of 5 units per day. For an enumeration method of this size, it requires 52,521 computational patterns while only 1,000 computational patterns are required by GA to find a near optimal solution. It shows that the profit of the chain generated by GA from 10 replications ($156,886) is very close to the optimal solution ($156,939) generated by the enumeration method with only 0.0338% in its difference less than the optimal solution suggested from the enumeration method with a lot shorter computational time.

In addition, the results of the centralized model of the actual study size under GA have been also checked with the results generated from the lower and upper bound settings of the decision variables. The result shows that the profit of the chain generated by GA ($6,322,137) is 10.5% and 34.9% higher than the profits generated at the lower bound setting ($5,720,950) and the upper bound setting ($4,686,367). Therefore, the solutions from GA in this study are sufficiently proven to produce good results.

## 3.5 Analysis and Comparison of the Results

One of the most important aspects in comparative studies is the fairness in comparison. There is no point to compare a good parameter setting system with a bad parameter setting system. Since GA is used to set appropriate levels of all decision variables or system parameters used to control the material ordering policy and inventory control system, all systems are then compared under the same basis. These comparisons are done, not only with the total profit of the chain but also the profits of each member.

This is to investigate an effect of introducing coordinating mechanisms in terms of financial incentives into different types of the supply chain and highlighting key contributions of such mechanisms. Then, the sensitivity analysis of the incentives is tested to check the rigidity of our conclusion.