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EVOLUTIONAL OPTIMIZATION ON MATERIAL ORDERING AND INVENTORY CONTROL OF SUPPLY CHAIN THROUGH INCENTIVE SCHEME

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Abstract

This paper studied the material ordering and inventory control of supply chain systems. The effect of controlling policies is analyzed under three different configurations of the supply chain systems, and solved by using evolutional method known as Differential Evolution (DE). The numerical results show that coordinating policy with incentive scheme outperforms the other policies and can improve the performance of the overall system as well as all members under the concept of supply chain management.

Keywords: supply chain management, inventory control, material ordering, differential evolution

1. INTRODUCTION

Recently industries have been focusing increasingly on the role of inventory in the supply chain facing with growing market and global competition. In order to determine the appropriate ordering quantity and inventory level among partners in the chain, it is important to find the suitable mechanism for coordinating the inventory processes that are controlled by independent partners (Prasertwattana and Chiadamrong, 2004a, b).

With this point of view, this study concerns with the material ordering and inventory control in three typical configurations of the supply chain, which are common in every industry namely, "single-manufacturer, single-retailer" chain (single dyadic chain), "single-manufacturer, multi-retailer" chain and "multi-manufacturer, single-retailer" chain. These three supply chain systems are operated under three controlling policies that consists of decentralized policy, centralized policy and coordinating policy with incentive scheme. The aim of this study is to find the proper coordinating mechanisms based on the exchange of incentives that can improve the overall performance of the chain as well as the individual performance of each member.

Since mathematical models describing these problems become very complex, so we apply an evolutional optimization method, which is amenable for the simulation-based approach, to solve the problems. For this purpose, Differential Evolution (DE) (Storn and Price, 1997) is employed to carry out all numerical experiments. In order to validate the solutions from DE, we compare its performances with Genetic Algorithm (GA).

2. MODEL DESCRIPTION

In what follows, three models of the supply chain systems concerned here will be described briefly. In all cases, we put the following assumptions.

1. The manufacturer uses the periodic review with safety stock and lot sizing policy to control its inventory.
2. The retailer uses the periodic review with target stock level (T, S) to control its inventory.
3. End customer's demand and delivery lead-time are randomly generated based on the normal distribution.
4. For both manufacturer and retailer, only one order is allowed to be placed at any period.
5. Production rate of the manufacturer is assumed fixed and higher than the mean demands.
7. Unfulfilled demand is considered as shortages without backordering.
8. The service level of the manufacturer (β_m) and the retailer (β_r) should be greater than 90%.

2.1 "Single Dyadic Chain" Problem

The members in this chain consist of one supplier, one manufacturer, one retailer and end customers as shown in Fig.1. However, only the relationship between the manufacturer and the retailer is considered (the supplier and end

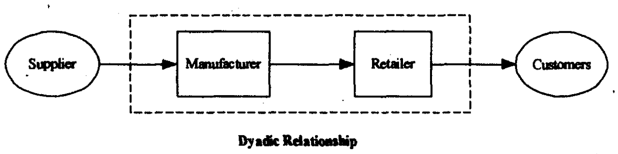

Fig.1 Single dyadic configuration

customers are considered as external members in the chain). The supply chain operates under the make-to-stock environment, in which stochastic demand and lead-time are considered. The supplier has unlimited production capacity. However, under uncertainty in the delivery lead-time, the supplier may delay the supply of raw materials to the manufacturer. Therefore, the manufacturer has to select the appropriate material ordering policy and may hold some safety stock of finish product to cope with the effect of uncertainty in demand and delivery lead-time. The retailer uses the periodic review with order up to the target stock level to control the inventory. The target stock level of the retailer 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 of products from the manufacturer. (See Tersine, 1994 for further information about the concept of inventory control).

Decision variables of this problem consist of material ordering policy and safety stock level of the manufacturer and target stock level of the retailer.

2.2 "Single-Manufacturer, Multi-Retailer" Problem

In some situations, the assumption of only one buyer may not be so realistic, especially when the manufacturer has a higher bargaining power, and has the ability to supply its product to more than one retailer (Fig. 2). Under multi-retailer case, if any shortage exists, the manufacturer must make a distributing decision to spread out a portion of available units on hand to a certain number of retailers. Special aspect for this system is to add the issue of the distributing strategy to the problem as the decision variable.

2.3 "Multi-Manufacturer, Single-Retailer" Problem

In some situation, the retailer has higher bargaining power in the chain. The retailer can select the appropriate approach to allocating order quantity among the suppliers or manufacturers. Special aspect for this system as shown in Fig.3 is to add the complexity of the order allocation (decision variable) to the problem.

3. STRATEGIC MANAGEMENT POLICY

The details of decentralized policy, centralized policy, and coordinating controlling policy with incentive scheme will be described in this section.

The inventory level of both manufacturer and retailer are reviewed at every periodic time t, (t = 1,2,.., T) over totally

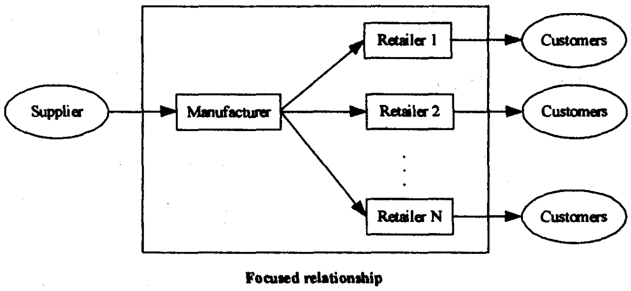

Fig.2 Single manufacturer and multi-retailer configuration

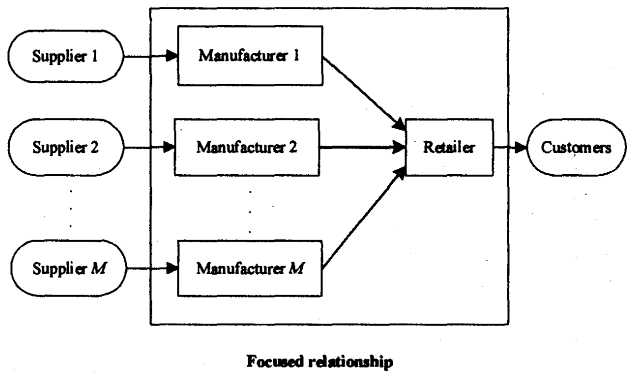

Fig.3 Multi-manufacturer and single-retailer configuration

T periods (planning horizons). Each period consists of interval of time Tp days. The following notations will be used in all models.

Parameters of manufacturer

Fd_t = Forecast demand per period without information sharing (under decentralized policy)
Fc_t = Forecast demand per period with information sharing (under centralized and coordinating policy)
lm_t = Real delivery lead time of raw material
lr_t = Real delivery lead time of product
L_m = Delivery lead time contract of raw material
L_r = Delivery lead time contract of product
PR = Production rate per day
Es_t = Ending stock on hand level of raw materials
Em_t = Ending stock on hand level of products
Ess_t = Ending safety stock level of products
Qm_t = Ordering quantity of raw materials
Qp_t = Production quantity of products
Qr_t = Sales volume of products of the manufacturer
Sm_t = Quantity of Shortage at the manufacturer
Om_t= Ordering decision equal 1 if order is placed, equal 0 otherwise

Cost parameter of the manufacturer

Dt = End customer demand per day
c_m = Unit purchasing cost of raw material
c_p = Unit production cost

c_{ht} = Unit holding cost of raw material that calculate from h_t % of unit purchasing of raw material c_m or $(c_m \cdot h_t)/100$
c_{hm} = Unit holding cost of product that calculate from h_m % of value of finished product or $((c_m + c_p) \cdot h_t)/100$
c_{sm} = Unit shortage cost
c_{om} = Ordering cost per period
c_t = Cost for activate fast delivery per period

Parameters of the retailer
Qc_t = Sales volume of product at the retailer
Qr_t = Ordering quantity of products at the retailer or sales volume of products at the manufacturer
Er_t = Ending stock on hand of products
Sr_t = Quantity of shortage at the retailer

Cost parameter of the retailer
c_r = Unit purchasing cost of product
c_a = Unit administration cost
c_{hr} = Unit holding cost of product that calculate from h_r % of unit purchasing c_r and administration cost c_a or $((c_r+c_a) \cdot h_r)/100$
c_{sr} = Unit opportunity lost cost
c_{or} = Ordering cost per period
c_b = Bonus cost per period
$sell_r$ = Sales price per unit of product

3.1 Decentralized Policy

In the decentralized policy, each member acts as a single decision maker aiming to optimize its own profits. Since there is no information sharing in the chain, the retailer directly faces with the end customer demands while the manufacturer receive only information about the past retailer's ordering quantity without knowing real end customers' demand. Therefore, we consider two different objective functions for the manufacturer and retailer respectively as follows.

3.1.1 Decentralized controlling policy under the manufacturer's perspective

The objective function of this model is to maximize the profit of the manufacturer (Πm).

$$Max\ \Pi m = \sum_{t=1}^{T} c_r \cdot Qr_t - \sum_{t=1}^{T} c_{ht} \cdot Es_t - \sum_{t=1}^{T} c_{hm} \cdot (Em_t + Ess_t) - \sum_{t=1}^{T} c_{sm} \cdot Sm_t - \sum_{t=1}^{T} c_m \cdot Qm_t - \sum_{t=1}^{T} c_p \cdot Qp_t - \sum_{t=1}^{T} c_{om} \cdot Om_t \quad (1)$$

subject to:

$$\beta_{mt} \geq 90\% \quad (2)$$

The manufacturer gets revenue from selling products to the retailer while the operating costs consist of holding cost of raw material, holding cost of product, shortage cost, purchasing cost, production cost and ordering cost. The manufacturer makes an order of raw material based on the lot sizing policy (decision variable). If T = 6 planning horizons, 32 possible ordering policies are existed. For example, the first policy may follow lot for lot policy or make an order in every period, the second possible policy may combine order of period 1, 2 and 3 and then use lot for lot for the rest three periods, and so on. Therefore, under second possible policy, the manufacturer has to pay the ordering cost only for period 1, 4, 5 and 6 (Om_1, Om_4, Om_5, Om_6 = 1), and can save the ordering cost for two periods (Om_2, Om_3 = 0). We assume that the manufacturer can start the production at the beginning of each period if raw material on hand is existed, otherwise the manufacturer has to wait until receives raw material from the supplier at time $t+lm_t$. As a consequence, the production quantity under the combine order condition may higher than lot for lot case that results in higher capability to supply retailer's demand (lower shortage cost) but incurs higher holding cost.

Even though the models in this study aims to maximize the profit, the customer satisfaction seems to be a major obligation. Therefore, the required service level constraint is added to the model and its lower bound is set at 90%.

3.1.2 Decentralized controlling policy under the retailer's perspective

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

$$Max\ \Pi r = \left(\sum_{t=1}^{T} sell_r \cdot Qc_t + \sum_{t=1}^{T} c_{sm} \cdot Sm_t\right) - \sum_{t=1}^{T} c_{hr} \cdot Er_t - \sum_{t=1}^{T} c_{sr} \cdot Sr_t - \sum_{t=1}^{T} c_r \cdot Qr_t - \sum_{t=1}^{T} c_a \cdot Qc_t - (c_{or} \cdot T) \quad (3)$$

subject to:

$$\beta_{rt} \geq 90\% \quad (4)$$

Revenue of the retailer comes from selling products to the end customers and receiving penalty cost of shortage paid by the manufacturer. The operating costs consist of holding cost of product, opportunity lost cost, purchasing cost, administration cost and ordering cost. The retailer reviews its inventory and makes an order at every periodic epoch time t, so the ordering cost is simply calculated by multiply ordering cost with the number of planning horizons. Again, the lower bound of the service level is set at 90%.

3.2 Centralized Policy

The traditional coordinating policy views the system as one entity and there is one central planner who makes all decisions to maximize the profit of the entire chain (Πs). Under this situation, the full information sharing is implemented and customer service level should be greater than or equal to 90%.

$$Max\ \Pi s = \Pi m + \Pi r \quad (5)$$

subject to:

$$\beta_{rt} \geq 90\% \quad (6)$$

3.3 Coordinating Policy

In this perspective, the retailers and the manufacturers agree to form a chain and exchange incentives to strengthen their relationship. Therefore, full information sharing is also implemented throughout the system. Under this policy, we focus on a situation where the manufacturers offer the discount d% (additional decision variable) to the retailer for each purchase unit beyond the break point A. The discount is an incentive that the manufacturer offers to the retailer to increase its sales volume. At the same time, the retailer offers a bonus to the manufacturer as an exchange. The bonus (B_t) is paid to the manufacturers only when the products are delivered to the retailer at the correct quantity ($Sm_t = 0$) and on time ($l_t = 0$). In order to prevent shortages, the manufacturer may need to keep more stock; also in order to deliver the product on time, the manufacturer may need to pay an extra cost (Ct_t) to gain extra effort for such activities. So the manufacturers will make a decision whether to accept ($B = 1$) or reject ($B = 0$) the bonus incentive (additional decision variable).

The objective function of this model is also aimed to maximize the profit of the chain (Π_{sj}), same as the centralized model. However, by adding bonus and quantity discount cost to the system, the formulations for calculating profit of the manufacturer (Π_{mj}) and profit of the retailer (Π_{rj}) are modified as follows:

$$\Pi sj = \Pi mj + \Pi rj \tag{6}$$

$$\begin{aligned}\Pi mj =& \Big(\sum_{t=1}^{T} c_r \cdot Qr_t + \sum_{t=1}^{T} B_t\Big) - \sum_{t=1}^{T} c_{ht} \cdot Es_t \\ & - \sum_{t=1}^{T} c_{hm} \cdot (Em_t + Ess_t) - \sum_{t=1}^{T} c_{sm} \cdot Sm_t - \sum_{t=1}^{T} c_m \cdot Qm_t \\ & - \sum_{t=1}^{T} c_p \cdot Qp_t - \sum_{t=1}^{T} c_{om} \cdot Om_t - \sum_{t=1}^{T} Ct_t\end{aligned} \tag{7}$$

$$\begin{aligned}\Pi rj =& \Big(\sum_{t=1}^{T} sell_r \cdot Qc_t + \sum_{t=1}^{T} c_{sm} \cdot Sm_t\Big) - \sum_{t=1}^{T} c_{hr} \cdot Er_t \\ & - \sum_{t=1}^{T} c_{sr} \cdot Sr_t - \sum_{t=1}^{T} c_r \cdot Qr_t - \sum_{t=1}^{T} c_a \cdot Qc_t - (c_{or} \cdot T) \\ & - \sum_{t=1}^{T} B_t\end{aligned} \tag{8}$$

where:

$$c_r = \begin{cases} c_r & \text{if } Qor_t \le A \\ ((c_r \times A) \\ \quad +(c_r)(Qor_t - A)(1-(\frac{d}{100})))/Qor_t & \text{otherwise} \end{cases} \tag{9}$$

$$B_t = \begin{cases} c_b & \text{if } B = 1 \text{ and } l_t \le 0 \\ 0 & \text{otherwise} \end{cases} \tag{10}$$

$$Ct_t = \begin{cases} c_t & \text{if } B = 1 \text{ and } l_t > 0 \text{ and } Sm_t = 0 \\ 0 & \text{otherwise} \end{cases} \tag{11}$$

$$\beta_{rt} \quad \ge \quad 90\% \tag{12}$$

4. SOLUTION TECHNIQUE

In single dyadic chain under decentralized and centralized policies, there are three decision variables, which are the discrete lot sizing of the manufacturer, the safety stock kept at the manufacturer, and the target stock level at the retailer. Then, the decision of the manufacturer to accept or reject the bonus, and quantity discount rate are added when the incentives are offered under coordinating policy. The last two decision variables that consist of the distribution of products to each retailer and order allocation of products to each manufacturer are belonged to "single-manufacturer, multi-retailer" and "multi-manufacturer, single-retailer" problems, respectively.

Due to insufficiency of traditional optimization techniques in solving such complicated models involving integer variables, we select to use the evolutional optimization methods like DE. The outline of only DE is given below.

Step1. Generate randomly every n-dimensional "*target vector*" to yield the initial population, an example of which chromosome is shown in Fig. 4.

$$x_{i,G} \quad (i = 1, 2, \ldots, M),$$

where subscript G is the generation number and M is the population size.

Step2. Create each "*mutant vector*" by adding the weighted difference between two target vectors to the third target vector. (These three vectors are chosen randomly among the population.)

$$v_{i,G+1} = x_{3,G} + F(x_{2,G} - x_{1,G}), (i = 1, 2, \ldots, M),$$

where F is a real and constant in [0,2].

Step3. Apply the crossover operation to generate the "*trial vector*" $u_{i,G+1}, (i = 1, 2, \ldots, M)$ by mixing some elements of the "*target vector*" with the "*mutant vector*" through comparison between random value and crossover constant (see Fig.5).

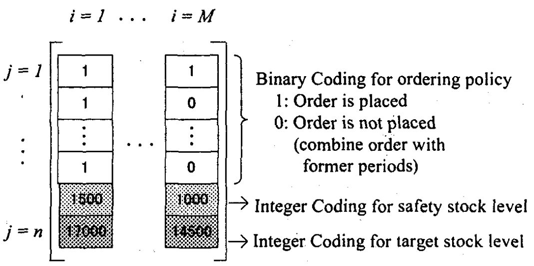

Fig.4 Example of DE's coding

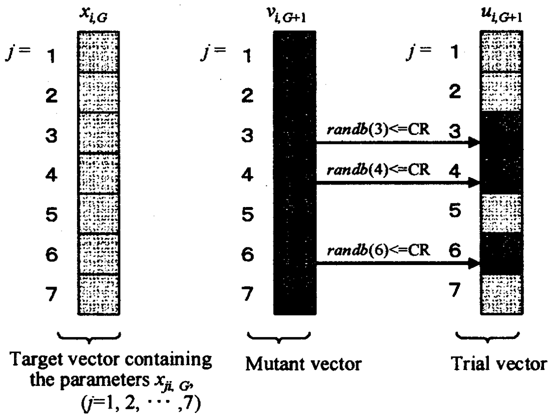

Fig. 5 Example of crossover process for $n = 7$

$$u_{ji,G+1} = \begin{cases} v_{ji,G+1} & if(randb(j) \le CR) \quad or \quad j = rnbr(i) \\ x_{ji,G} & if(randb(j) > CR) \quad and \quad j \ne rnbr(i) \end{cases}$$

$$j = 1, \cdots, n$$

where $randb(j)$ is the jth evaluation of a uniform random number generator, CR is the crossover constant $\in [0,1]$, and $rnbr(i)$ is a randomly chosen index in $\{1, 2,..., n\}$ which ensures that $u_{i,G+1}$ gets at least one parameter from $v_{i,G+1}$. Then, evaluate the performance of each vector.

Step 4. If the "*trial vector*" is better than the "*target vector*", the "*trial vector" replaces the "target vector*". Otherwise, the "*target vector*" is remained. Therefore, the members of the new population for the next generation will be selected in this step.

Step5. Check the pre-specified stopping condition. If it is satisfied, stop and return the overall best vector as the final solution. Otherwise, go back to *Step 2* by incrementing the generation number by 1.

5. NUMERICAL EXPERIMENTS

Numerical experiments are carried out under the following conditions and use input parameters as shown in Table 1. End customer demands per day at each retailer and delivery lead-times are randomly generated under the normal distribution. For DE, population size = 20, constant of mutation (weight) = 0.9 and crossover constant = 0.5. Stopping generation of single dyadic chain, multi-retailer chain and multi-manufacturer chain = 3000, 10000 and 10000, respectively.

To examine the performance of DE, we applied also GA to solve the problems (Prasertwattana and Shimizu 2005). For GA, the crossover rate and mutation rate = 0.5 and 0.2, respectively. The other values are set as same as DE.

5.1 Comparison of the Results between DE and GA

A comparison of the results between DE and GA are shown in Fig.6. This figure illustrates the profit of the entire chain of "single-manufacturer, multi-retailer" problem with three different controlling policies. The result shows that DE can attain the better profit than GA for every case with shorter computation time (within at most several seconds using recent ordinary PC). This is because the binary coding employed by GA makes the length of chromosome extremely long according to the increase in the number of decision variables. In contrast, DE needs only the same number of length as the decision variables. Relying on this fact, we will discuss the consequences based on the results obtained only from DE hereinafter.

Table 1 Parameter employed in numerical experiment

Input parameter	**Value**
D_t, Fc_t	Normal (1000, 250^2) units per day
Fd_t	Normal (1000, 350^2) $\times T$ units per period
lm_t, lr_t	Normal (2, 1^2) days
L_m, L_r	2 days
PR	2000 units per day
T	6 periods
Tp	10 day
Cost parameter	**Value**
c_{om}, c_{or}	$500 per order
c_m	$150 per unit
c_p	$350 per unit
ht	1.5% of raw material value
hm, hr	2% and 3% of product value
c_{sm}	$15 per unit
c_t	$1,000 per period
c_r	$570 per units
c_a	$100 per units
hr	3% of product value
c_{sr}	$20 per units
c_b	$15,000 per period
$sell_r$	$760 per units

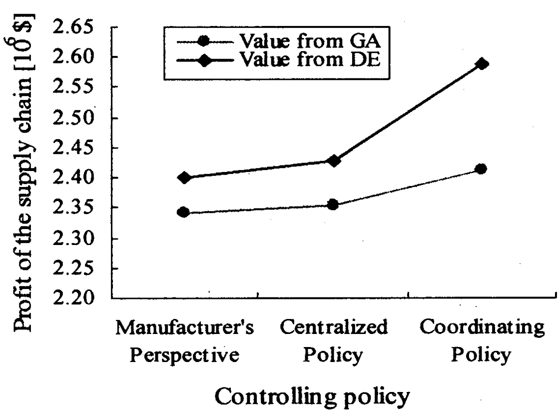

Fig. 6 Comparison of the results between DE and GA

5.2 Result of Single Dyadic Chain Problem

Without information sharing under the decentralized policy, the manufacturer has to forecast the demand based on its local information and is usually faced with the problem of error production setting. By introducing the centralized policy with full information sharing to the system, the financial performance of the manufacturer and the chain are improved compared with the case of the manufacturer's perspective as shown in Fig.7.

However since the retailer always get the information at the point of sale, sharing full information has less influence on the retailer. So the centralized policy fails to improve the performance of the retailer when compared with the case under the retailer's perspective. Then an incentive scheme is introduced as a coordinating mechanism between partners in the chain. As a result, the profit of all partners and the chain can be increased, or it becomes to achieve a win/win situation.

5.3 Results of "Single-Manufacturer, Multi-Retailer" Problem and "Multi-Manufacturer, Single-Retailer" Problems

The manufacturer tends to dominate the chain under "single-manufacturer, multi-retailer" problem. When the aim is to maximize the profit of only one party, it generates the lowest profit of the chain in comparison with the other policies as shown in Fig 8. When the aim is to maximize the profit of the entire chain as in the case of the centralized policy, it is found that the profit of the whole chain can be increased. However, no improvement on the manufacturer's profit in this case may prevent the manufacturer from forwarding the plan. In contrast, by virtue of exchanging incentives among the manufacturers and the retailers, a win/win game for all parties can be achieved as known from the result of coordinating policy.

Moreover, the results of "multi-manufacturer, single-retailer" problem are come out to be the same as "single-manufacturer, multi-retailer" problem that the coordinating policy can generated the best profit for all members and the supply chain system.

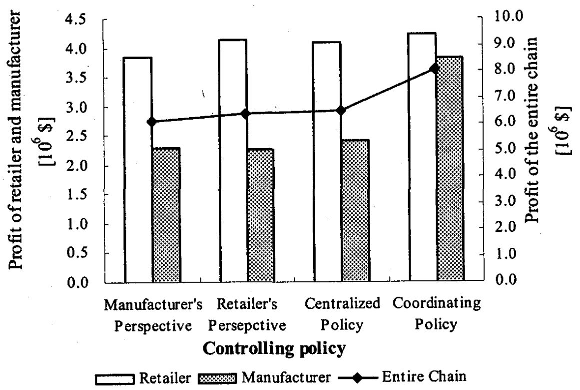

Fig. 7 Comparison of profits among the members and the chain ("single dyadic chain")

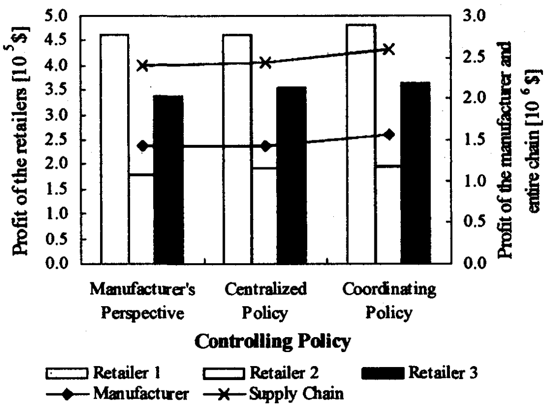

Fig. 8 Comparison of profits among the members and the chain ("single-manufacturer, multi-retailer")

6. CONCLUSIONS

This paper presented the material ordering and inventory control policies of single dyadic chain, "single-manufacturer, multi-retailer" as well as "multi-manufacturer, single-retailer" problems. By implementing the evolutional methods like DE and GA to solve the problems, it reveals that both methods can solve favorably the complicated mathematical models, but DE outperforms GA in accuracy of the resulting solution. The results of the numerical experiments illustrate that the incentive scheme introduced in the coordinating policy can generate a win/win situation for all members and improve the performance of the entire chain for all three configurations of supply chain systems.

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