27

Study of Flexibility and Adaptability in Distributed Supply Chains

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1. Introduction

Uncertainties in demand and supply, which are two major contributions to system dynamics, are unavoidable attributes in supply chains. Agent technology has been a renowned enabler to achieve flexibility and adaptability, which are regarded as the distinctive characteristics of future supply chains, to overcome system dynamics (Chan and Chan, 2005). In order to testify the usefulness of these characteristics, a series of simulation study have been conducted by the authors to investigate the effects of these two characteristics on distributed supply chains, which are subject to uncertainty. In fact, this article aims at presenting the simulation results and drawing conclusion in relation to these two characteristics on supply chain dynamics.

The research motivation of this article originates from two reported research. Chan and Chan (2005) performed a survey on related literature, and concluded that agent technology would be a potential problem solver in modelling future supply chains. They then developed a multi-agent based simulation model for supply chains (Chan and Chan, 2004). By making use of this model, they followed the same line of research direction by introducing flexibility and adaptability through coordination mechanisms in their investigation. As a pilot study, a simulation study with the said flexibility in a single product environment has been reported (Chan and Chan, 2006). This chapter further extends their study with focus on a multi-product environment. Simulation results indicated that introduction of flexibility in due date and quantity is able to reduce the total cost of the system under study, as compared with traditional stochastic model which makes use of safety stock to counteract with system dynamics. Like flexibility, additional adaptability could be able to improve the performance of the supply chain further, with even better improvement.

The organisation of the rest of this chapter is as follows: Section 2 presents re-

Source: Manufacturing the Future, Concepts - Technologies - Visions , ISBN 3-86611-198-3, pp. 908, ARS/plV, Germany, July 2006, Edited by: Kordic, V.; Lazinica, A. & Merdan, M.

lated literature. The research methodology, i.e. the simulation model, will be briefly explained in Section 3. Simulation results and key findings will be discussed in Section 4 to Section 6: results with respect to flexibility study are summarised in Section 4; effects on information sharing will be discussed in Section 5; and results in regards to adaptability will be presented in Section 6. Section 7 is the concluding section for future research direction.

2. Literature Review

2.1 Distributed Problem Solving in Supply Chains

Supply chain can be viewed as a network of participating corporations working together to achieve the system goals. It can be defined as a "connected series of activities which is concerned with planning, coordinating and controlling of materials, parts and finished goods from supplier to customer" (Stevens, 1989). Supply chain management aims at optimising all activities through the supply chain, so that products and services are supplied in the right quantity, to the right time, and at the optimal cost. In this connection, coordination among supply chain members is of vital importance. Due to the distributed nature of global supply chain, agent technology has been employed to model supply chains in some reported literature. As a matter of fact, agent technology provides channels for integrating the independent echelons of the entire supply chain as a networked system (Gjerdrum *et al.*, 2001). Mutli-agent system (MAS), a branch of Distributed Artificial Intelligence, consists of more than one autonomous agent. One of the critical research challenges in a large portion of agent-based applications is coordination (Tambe et al., 1999).

MAS is a typical example of distributed problem solving technique that gains high attention in recent supply chains research. Swaminathan et al. (1998) presented a multi-agent approach to model supply chain dynamics. They developed a supply chain library of software components such that customised supply chain models can be built from the library. Sadeh et al. (2001) presented an agent-based architecture for dynamic supply chain called MASCOT (Multi-Agent Supply Chain cOordination Tool). MASCOT is a re-configurable, multi-level, agent-based architecture for coordinated supply chain. Agents in MASCOT serve as wrappers for planning and scheduling modules. Above mentioned researches are focusing on the architectural issues and lacking of higher coordination mechanism, which is a common weakness in many agent-base research in the supply chain domain. One reason may due to the fact that coordination is more problem specific and it is not easy to generalise a theory for different supply chains. Nevertheless, agents in a MAS is loosely coupled and are not controlled by a central controller, it is easy to loss distributed functions. Coordination is an effective tool to prevent the system from such problem, i.e. chaotic behaviour in agent's terminology.

2.2 Information Sharing in Supply Chains

Information transfers among independent companies in supply chains tend to be distorted and can be misguided up-stream members regarding their inventory and production decisions, which is the well known Bullwhip Effect (Lee *et al.*, 1997). It is commonly believed that information sharing may reduce the impact of demand uncertainty (Lin et al., 2002). However, information sharing among companies is not always possible because of privacy of corporate information, and trust among corporations. In addition, incompatibility among heterogeneous information systems can also hinder information sharing among them. Therefore, information sharing has been over-emphasised as a generic cure for supply chain dynamics (Raghunathan, 2001).

After Lee et al. (1997) had coined the Bullwhip Effect, Lee et al. (2000) conducted another study to analyse how information sharing can improve the supplier's order quantity decision in a two-level supply chain, with a known autoregressive demand process. In respond to their study, Raghunathan (2001) showed that the manufacturer could make use of its own information with respect to the entire order history in order to reduce the variance of its forecast. As a consequence, there is no need to make investment for sharing information. More research on information sharing with respect to supply chains can be found. Cachon and Fisher (2000) studied a supply chain subject to stationary stochastic demand. They compared a traditional information policy that does not use shared information against a policy with full information sharing. They observed that share information among supply chain members could reduce cost. They, however, argued that implementing information technology to accelerate and smooth the physical flow of goods through a supply chain, i.e. simply flowing goods through the supply chain more quickly and more evenly, may produce greater improvement than sharing information.

2.3 Coordination in Supply Chains

Quantity / price discount is a common strategy to provide coordination channel among supply chain members. Quite a lot of research could be found with respect to discount policy. For example, Viswanathan and Piplani (2001) considered an incentive policy such that a vendor offers a discount to buyers if they place orders only at the times as specified by the vendor. One common weakness of the reported research with such channel coordination is that deterministic demand is assumed. Therefore, impact of system dynamics on the proposed model has not been studied. Facing uncertain demand, for example, retailers prefer to place an order late in most case in order to gather enough time to collect more information (Chen and Xu, 2000). However, this leads to insufficient production times and hence production cost would probably be increased.

Coordination can also exist in the form of contracting. Quantity flexibility contract "provides flexibility with no explicit penalty for exercise, by adopting constraints as a way to motivate appropriate behaviour" (Tsay, 1999). By introducing quantity flexibility, the retailer can place an order earlier due to the flexibility that is introduced in the quantity range and the supplier may only need to finish the order with quantity that is within the committed range. In addition, the retailer may request less quantity of goods to be shipped if the actual demand is lower than what is expected. This philosophy, which is also the research direction of this study, can provide incentive to both supplier and retailer.

2.4 Research Direction

Effective coordination strategies will be very important for agents in next-generation of multi-agent systems (Lesser, 1998). These agents will need to be highly adaptive due to their ''open'' operating environments where the configuration and capabilities of other agents and network resources could be changed dynamically. One of the ways that such agents can be adaptive is to consider multiple ways of solving their sub-problems so that they can adjust their solution to produce the best possible result, subject to the restrictions on available processing, communication, and information resources, etc. In fact, quantity flexibility as proposed in this study is one of the possible ways to provide agents with a set of possible solutions so that the best solution could be finalised dynamically through the proposed coordination mechanism.

Agents can also be more adaptive if they are not restricted to solving one goal at a time, but are able to flexibly arrange their activities to solve multiple goals concurrently. This is exactly the idea of the proposed adaptive coordination mechanism in this study.

Based on these findings, Chan and Chan (2006) studied the effects of demand and supply uncertainties as independent variables in an agent-based supply chains with single product type, and suggested a coordination mechanism with quantity flexibility to react with such uncertainties. It was found that the performance of the supply chain under studied outperforms the same one with stochastic model, where the performance measures are total cost. This study is a natural extension of previous Chan and Chan's work (2006) whereas multi-product supply chain system will be studied here. By employing the same quantity flexibility approach to the said system, it is found that total system cost is improved when compared with the stochastic model, which is in line with their findings.

In addition, the effects of information sharing on the proposed coordination mechanism have been studied as a benchmark. Finally, adaptability nature has also been added in the proposed mechanism in order to further improve the system performance.

3. Supply Chain Model

3.1 The Agent-based Model

As mentioned before, this study makes use of the agent-based model which was developed by Chan and Chan (2004). Since the main focus of this article is not on the agent-based model, only a brief sequence diagram as quoted in Chan and Chan (2006) is included as in Fig. 1. For detail discussions on the agent-based model and associated operations, please refer to Chan and Chan (2004). The agent-based simulation program was written in JAVA.

Description of events	**Agent which announces the job**		**Other agents**
[a] Order is needed, announce job to other agents	Job Announcement Agent	→	Job Reception Agent
[b] Job Reception Agent relays the job to Bid Evaluation Agent			↓
[c] Other agents are considered to submit a bid			Bid Evaluation Agent ↓
[d] Other agents submit a bid according to their own conditions	Bid Reception Agent	←	Bid Evaluation Agent
[e] Deadline for bid submission is reached (no more bids will be accepted)	Bid Reception Agent		
[f] Notify Job Award Agent	↓		
[g] Job Award Agent sends offer to other agents according to the ranked bids	Job Award Agent	→	Bid Evaluation Agent
[h] Acknowledge of job offer	Job Award Agent	←	Bid Evaluation Agent
[i] Contract is made	↓ Incoming Contract Agent		↓ Outgoing Contract Agent

Figure 1. Simplified sequence of operations among agents (Source: Chan and Chan, 2006)

3.2 The Supply Chain

In the simulation study, the model consists of three customers and four suppliers. Total number of product types is three. Simulation study has been carried out to verify the usefulness of the proposed flexibility and adaptability concept. Length of simulation is 465 periods while the first 100 periods are ignored for calculation in order to minimise the start-up effect. The final performance measures are based on the last 365 periods (i.e. T = 365). If one period is equal to one day, then the effective length of simulation run is one year. Each simulation setting will be run with 10 different random seeds and the average is reported in order to minimise the random effect. Together with the 16 sets of independent variables (to be discussed in Section 3.3), a total of 160 simulation runs were carried out for each strategy. Since there are 3 sets of strategy, total number of simulation runs is 160 x 3 = 480 sets. In fact, more simulation runs have been conducted (e.g. against different capacity levels as discussed in Section 3.3.), however, only the two independent variables are the main focus of this study.

3.3 Dependent and Independent Variables

Total system cost is recorded as the dependent variable for comparing different coordination mechanisms.

Setting	Demand Uncertainty	Supply Uncertainty
1	1	1
2	1	2
3	1	3
4	1	4
5	2	1
6	2	2
7	2	3
8	2	4
9	3	1
10	3	2
11	3	3
12	3	4
13	4	1
14	4	2
15	4	3
16	4	4

Table 1. Different settings of the simulation study

On the other hand, there are two independent variables in this study, namely, demand uncertainty and supply uncertainty (i.e. variation of capacity of each supplier). Each of these variables is modelled by varying the variance of the corresponding Normal distribution at four levels (from 1 to 4 where 1 means the least uncertain and 4 is the most uncertain). Therefore, there are 16 sets (4 x 4) of different simulation runs for each strategy as summarised in Table 1 in regard to the demand and supply uncertainties. Different settings mean different combination of uncertain demand and supply as shown in Table 1. The higher the number, the higher is the degree of uncertainty as expressed in terms of variance (or standard deviation) of the associated Normal distribution. In addition, capacity level is also modelled as the third independent variable. However, only representative results will be presented since this parameter is relatively insensitive with respect to this study.

4. Simulation Results with Flexibility

4.1 The Coordination Mechanism

In the order-up-to stochastic model, the so-called order-up-to level in fact consists of a basic quantity plus a safety stock, as illustrated in equation (1):

$$S = \mu (T_o + L) + \upsilon \sigma \sqrt{(T_o + L)} \qquad (1)$$

where, S is the re-order level;
μ is the mean of demand;
σ is the standard deviation of demand;
υ is the service level that the retailer would like to achieve;
T_o is the review period;
L is the order lead time.

The rationale behind is to use the safety stock (the latter term in equation (1)) as a buffer to compensate the effect of uncertainties. An order is placed every T_o period and the ordered quantity, Q, is the difference between S and the the inventory position, which is the sum of all exisitng inventory or backordered inventory and the total ordered quantity in all outstanding orders, below this re-order level. Therefore, the stochastic model inherently increases inventory cost. Intuitively, the stochastic model is not dynamic enough because demand is unpredictable due to its random nature. In this connection, quantity flexibility is introduced in the coordinated model in order to provide the flexibility to the retailer, as well as suppliers to react with system dynamics. In order to apply this coordination mechanism, the supply chain members must be coordination oriented, but no explicit information sharing is required. In the coordinated model, similar procedures are followed as in the stochastic model, with the following alteration:

In order to simply the following dicussion, the following discussions only foucs on a single product environemnet as in Chan and Chan (2006), but the same analysis applied to multi-product environemnt. When a job is announced, it consists of a range of quantities required instead of a fixed quantity. Equation (1) can be rewritten as the following equations:

$$S = \mu\,(T_o + L) + \upsilon\,\sigma\,\sqrt{(T_o + L)} = A + B \qquad (2)$$

$$A = \mu\,(T_o + L) \qquad (3)$$

$$B = \upsilon\,\sigma\,\sqrt{(T_o + L)} \qquad (4)$$

The range of quantity Q is defined such that:

$$Q \in \left[A - B, A + B\right] \qquad (5)$$

Equation (5) defines the "domain" of the variable "quantity" that the retailer requires the supplier to be shipped. In addition, the retailer will calculate a range of delivery dates so that supplier should ship the quantity as defined in equation (5) within the range of deliver due dates. The range can be defined as in equation (6):

$$\begin{aligned}&[\textit{Expected Delivery Due Date} - (B / \mu),\\ &\text{Expected DeliveryDue Date} + (B / \mu)]\end{aligned} \qquad (6)$$

where *Expected Delivery Due Date* is given by equation (7):

$$\textit{Expected Delivery Due Date} = D_{it} + \frac{Q}{\textit{Mean Capacity}} \qquad (7)$$

where D_{it} is the longest due date of supplier i at period t in its outstanding order
Q is the difference between S and inventory position

Refer to the above discussion, the range of quantity is set in relation to the safety stock, B, in the stochastic model. Therefore, an apple-to-apple comparison can be made between the proposed coordination mechanism and the stochastic model, which was employed as benchmark in later discussions. In fact, sensitivity analysis of this value (i.e. a small variation from B) has been conducted. In addition, different settings of the value of B (e.g. such as expressed as a percentage of the base quantity A) have been conducted as well. It was found that the results and trends of improvement are consistent with whatever value of B, with small difference in magnitude of the performance metrics, of course. Therefore, only the results with one-side wide equal to the safety stock is presented in this chapter.

The remaining procedure is the same as the stochastic model until lower bound of the due date in equation (6) of an outstanding order reaches. The retailer starts to coordinate with the supplier when and how many to be shipped. This turns out to define the final values of two variables – one is quantity Q, and the other is the date for shipment D. The two variables are distributed among the retailer and supplier under contract. Domain of Q is given by equation (5) and let Q_{low} (i.e. A – B in equation (5)) and Q_{high} (i.e. A + B in equation (5)) be the lower bound and upper bound respectively. Domain of the date for shipment is given by equation (6) and let D_{low} and D_{high} be the lower bound and the upper bound respectively. The objective is to solve this problem through a coordination mechanism. An outline of pseudo code is illustrated in Fig. 2.

```
t = t + 1;
coordination( )
    if (t∈ [Dlow, Dhigh]) then … (i)
        if (t = Dhigh) then  … (ii)
            Iit = get supplier inventory( )
            if (Iit ∉ [Qlow, Qhigh]) then … (iii)
                penalise supplier ( )
            exit( )
```

```
        else if (I_t = get my inventory ( ) > μ) then … (iv)
            exit ( )
          else
            I_it = get supplier inventory( )
            if (I_it ∉ [Q_low, Q_high]) … (v)
              penalise supplier ( )
            exit ( )
    else
        exit( )
end coordination ( )

get supplier's inventory( )
    if (t∈ [D_low, D_high]) then
        I_t = get my inventory ( )
        if (I_it > Q_high)
        I_it = Q_high
    else
        exit ( )
    return I_it
end get supplier's inventory( )
```

Figure 2. An outline of pseudo code for coordination (Source: Chan and Chan, 2006)

Condition (i) in Fig. 2 constrains the coordination to be taken place only if the due date is within the domain in equation (6). Condition (ii) ensures the coordination phase is ended when the upper bound of the due date in equation (6) reaches. In such case, outstanding order must be completed. Condition (iv) makes sure the retailer does have enough inventory if no shipment is made when D_{high} is not reached. Please note that conditions (iii) and (v) of the pseudo code allow the supplier to supply with quantity less than the defined domain, subject to penalty being incurred, if the inventory of the supplier less than the lower bound as stated in equation (5). This is a constraint relaxation and hence the new domain of Q is effectively become $(0, Q_{low}]$, i.e. any positive integer below Q_{low}. The reason to accept this argument is to ensure that the mechanism is complete and sound, i.e. the algorithm can always returns a solution. Of course, both the retailer and the supplier would not like to relax the constraint, if if possible, because both will suffer – the retailer gets less product and the supplier makes a loss due to the penalty.

4.2 Simulation Results

Fig. 3 depicts the percentage improvement of the proposed coordination mechanism with quantity and due date flexibility as compared with the stochastic model in terms of total cost. Positive values mean the proposed coordination mechanism could reduce the total cost as compared with the stochastic counterpart under different settings. Please note that three groups of results could be found in Fig. 3. They are actually the results from different capacity level as sensitivity analysis. In fact, the results concur the results as in Chan and Chan (2006), which only study a supply chain with single product type.

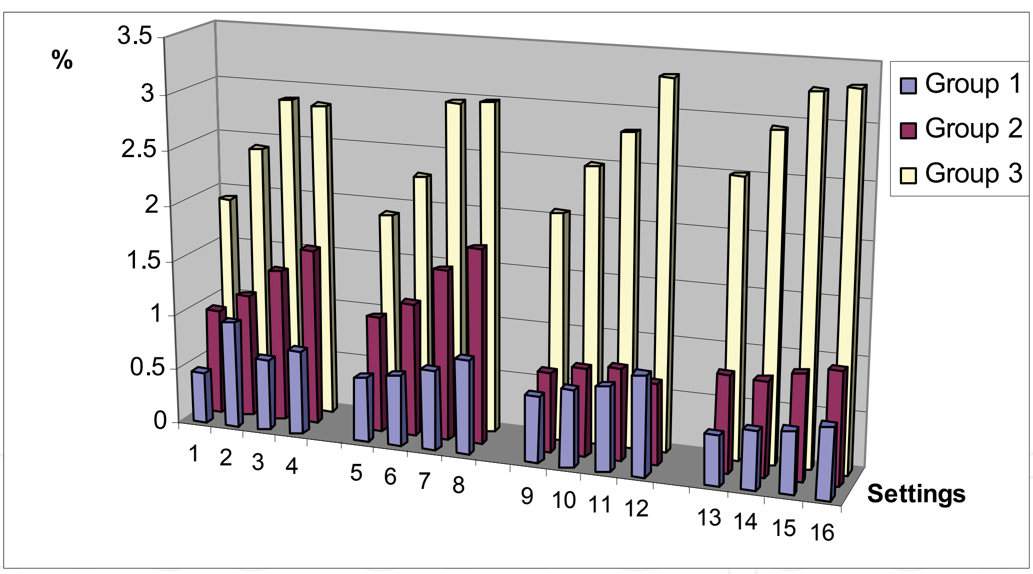

Figure 3. Percentage improvement of the coordination mechanism with flexibility against the stochastic model

5. Simulation Results with Information Sharing

As discussed in Section 2, information sharing is regarded as a solution facing system dynamics. The main objective of this section is to investigate whether the proposed coordination mechanism with flexibility could only perform better than the one with flexibility and information sharing together. Not surprisingly, the answer is "no". However, the difference may not be so significant if the technical constraints of implementing information sharing (e.g. investment and trust) are taken into considerations. In fact, if we consider the stochastic model is the lower bound of the model under study we could assume the model with information sharing is the upper bound, in terms of improvement subject to system dynamics.

5.1 The Coordination Mechanism

The coordiation mechanism with flexilibity in Section 4 assumes no information sharing among agents. The main focus of this section is to relax this assumption and compare the effects of two information sharing schemes. The rationale of allowing information sharing together with the coordination mechanism with flexibility is due to the fact that supplier may not need to produce the upper bound of the quantity range of a certain product type for a particular contract. This is because the customer turns out may request the supplier to ship less and hence excessive inventory may produce. If a supplier can complete a contract at a proper level, though the supplier may not necessarily ship the product according to the contract terms as defined in the coordination mechanism, slack capacity for next order can then be "created".

Two negotiation-based information sharing schemes are studies. They are:

(i) NEG1

only the inventory information of the customer and the supplier who are involved in the negotiation can share information. When the middle of the quantity range reaches, the supplier sends a message to the customer to ask for inventory level. The supplier makes the decision based on the total inventory level of the customer and the supplier to decide stop production or not. In fact, decision is made based on the expected total cost in a short time horizon. Equations (8) and (9) give the total cost of a customer j (Z_j)and supplier i (Z_i) over a period of time T respectively:

$$Z_j = \sum_{t=1}^{T} \sum_{p} (h_{jp} I_{jpt} + b_{jp} B_{jpt}) \quad (8)$$

$$Zi = \sum_{t=1}^{T} \sum_{p} h_{ip} I_{ipt} \quad (9)$$

where h_{jp} is the unit inventory holding cost per period of product type p of customer j

h_{ip} is the unit inventory holding cost per period of product type p of supplier i

b_{jp} is the unit backorder cost per period of each product type p of customer j

I_{jpt} is the inventory level of product type p of customer j at period t

B_{jpt} is the backorder level of product type p of customer j at period t

I_{ipt} is the inventory level of product type p of supplier i at period t

Assume current period is at $t = 1$ and T is the deadline of the order or contract under consideration. In each negotiation cycle, the supplier develops a matrix of $T \times T = \{C_{xy}\}$ such that x and $y = 1$ to T. Each element is the expected total cost (i.e. $Z_j + Z_i$) such that production is stopped at time x, and the contract is finished and delivered at time y. I_{jpt} and I_{ipt} are reduced or increased, if needed, according to the mean demand of the customer and mean capacity of the supplier respectively. Invalid elements are marked so that they are not eligible for later decision. From this matrix, the supplier can recognise the short term total cost and then is able to select the one with the lowest cost as the decision at this period. In other words, if it is not suggested to stop production at this period, the supplier will continue to produce a product and then reiterate the same negotiation at each period, i.e. update the matrix and reduce the size every period, until T is reduced to 1. Of course, the final delivery date depends on the retailer as well, which is governed by the original coordination mechanism.

(ii) NEG2

inventory information of all agents in the systems are sharable. Same as NEG1, when the middle of the quantity range reaches, the supplier sends a message to the customer for collecting all information on the inventory level of other agents. After the customer gathers all information, it is passed to the supplier. The supplier makes the decision based on the total inventory level of the all agents to decide stop production or not. Therefore, the cost equation is exactly the same to the one in NEG1, but all agents are taking into consideration. Strictly speaking, this information sharing scheme is not really "full" information sharing because only inventory information is available. However, "full" is in respect of the inventory level. Decision making is the same as the one as in NEG1.

5.2 Simulation Results

Fig. 4 illustrates the percentage improvement of NEG1 and NEG2 as compared with the coordination mechanism with flexibility only. It was found that both information sharing scheme with flexibility outperforms the coordination mechanism with flexibility only. Although both NEG1 and NEG2 could reduce the total cost further, it could not be concluded that neither NEG1 nor NEG2 is the best one. In other words, both information sharing scheme with flexibility perform comparably in terms of total cost, and no single information sharing scheme is the dominant policy. In addition, the further cost reduction is not that significant, especially at the left hand side of the graph, at which demand is less uncertain. Some further improvement is even lower than 10%. Considering the investment that has to make to achieve information sharing, information sharing may not be that attractive because of its insignificant improvement in certain settings. However, if the demand variability is high (i.e. at the right hand side), it is still a good policy to overcome the impact of system dynamics.

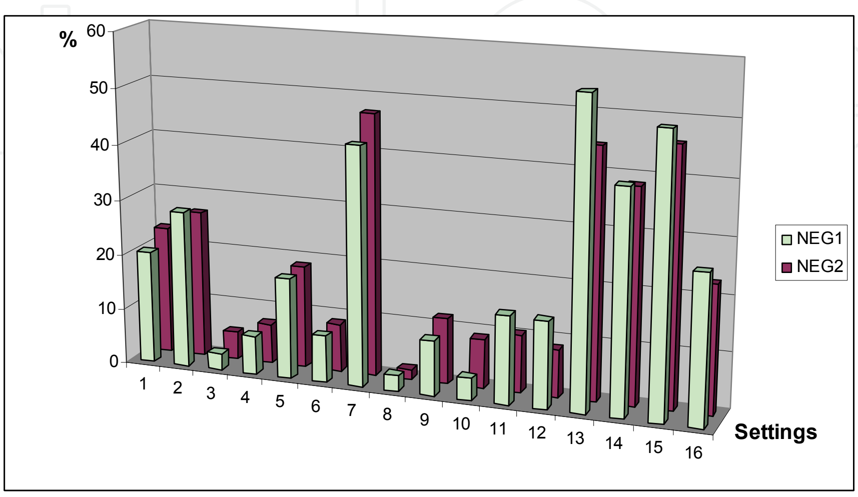

Figure 4. Percentage improvement of the two information sharing mechanism with flexibility against the coordination mechanism with flexibility only

The simulation results also support the argument at the very beginning of this section: If the stochastic model is the lower bound for benchmarking the performance of the coordination mechanism with flexibility, information sharing would be the upper bound.

6. Simulation Results with Flexibility and Adaptability

6.1 The Coordination Mechanism

This section summarises the principle of the adaptive coordination mechanism. As described in Section 5 above, the suppliers in fact have flexibility to allocate slack capacity for producing the next order to be processed on hand, as compared with a fixed quantity in the stochastic order-up-to policy. The rationale behind the proposed adaptive coordination mechanism is to "create" slack capacity artificially. In other words, production process of a product would stop before the maximum quantity is produced and switch to produce the product of the next planned order. One may argues if the supplier stop production of the current order at the minimum quantity of the range would results in more slack. However, this would only result in shorter and shorter ordering cycle because customers keep receiving less quantity in each ordering cycle. Therefore, a balanced scheme has to be designed in order to come up with a compromise between production quantity of the current order and the slack capacity for next order.

With information sharing as discussed in Section 5, this is relatively easy to achieve. However, without information sharing, an additional adaptive coordination mechanism is desired. In other words, the adaptive coordination mechanism helps the customers and suppliers to make the following decision: When should a supplier stop production of a product if the lower bound of the quantity range of the current order reaches, and then switch to production for next order? In the original coordination scheme, the customer takes the initiative to request completion of an order, unless deadline of a contract is due. In the adaptive coordination mechanism, this assumption is relaxed.

The supplier is able to send a similar request to the retailer once the supplier has produced middle of the quantity range in a contract, provided that the supplier has another outstanding. This is a signal to the customer that the supplier would like to stop production of the current order at a quantity lower than the upper limit of the contract. Since half of the range is equal to the safety stock quantity, the customer then calculate the deviation of its current inventory level (i.e. I_{jpt}) from the safety stock and take one of the following actions:

(i) If the difference is positive which means customer's inventory level is higher than expected, then, the customer accepts the supplier's request. However, shipment is not made instantly. It still follows the original coordination mechanism because the customer still has the flexibility to request for shipment. In other words, the supplier who made the request is suffering from inventory cost for a short period of time.

(ii) In contrast, if the difference is negative, the customer would refuse the request and then shipment, as in the case (i) still governed by the original mechanism.

This scheme is adaptive because decision is based on the real-time situation, rather than on the planned schedule. Together with the quantity flexibility that is introduced, the overall scheme is flexible and adaptive.

6.2 Simulation Results

Fig. 5 depicts the simulation results in regard to the adaptive coordination mechanism.Basically, the proposed adaptive coordination mechanism with flexibility performs better than the one with flexibility only at different settings and different parameters.

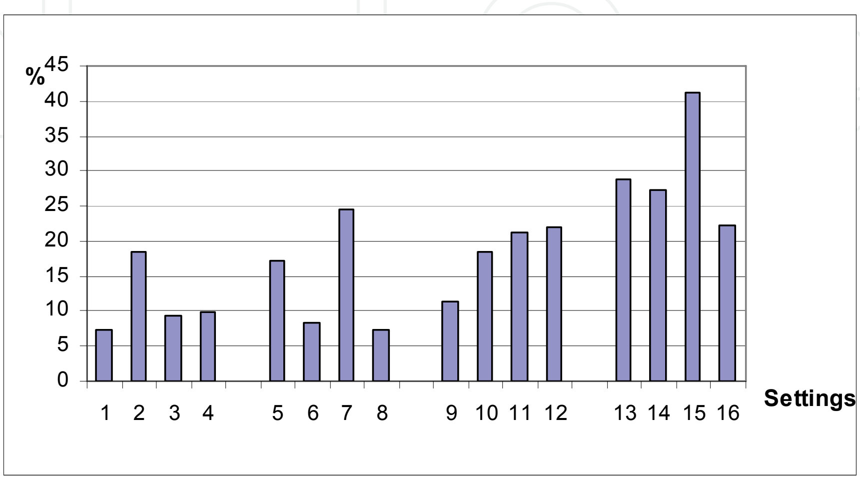

Figure 5. Percentage improvement of the adaptive coordination mechanism with flexibility against the coordination mechanism with flexibility only

However, only the percentage improvement in total cost of one instance is shown in Fig. 5 for simplicity. From Fig. 5, it is clear that the adaptive coordination mechanism outperform the one with flexibility only in all settings. In addition, results are even more promising at high demand uncertainty, i.e. the right-hand-side of Fig. 5.

7. Conclusions

A number of managerial implications could be drawn from this simulation study. They can be highlighted as below:

1. The core contribution of this study is introduction of flexibility and adaptability nature through a coordination mechanism for distributed supply chains in inventory management so that delivery decision (how many and when) of outstanding order is negotiable. This dynamic nature is proven, through simulation study, to be effective in reducing total system costs. Although traditional stochastic modelling is a means to reduce the total system cost by establishing safety stock in the system, it is not dynamic enough when the system is facing uncertainties. With the help of advanced information technology, the proposed mechanism is not difficult to implement.
2. By investigating the effects of information sharing as discussed in this paper, we found that information sharing with flexibility could perform even better in term of cost reduction as compared with the coordination mechanism with flexibility alone (and hence also better than the stochastic model). However, partial information sharing may perform considerably well as compared with full information sharing, subject to the same flexibility. By considering the investment and technical limitation of full information sharing (e.g. trust), it is not necessarily to pursue full information sharing all the time.
3. Regarding information sharing, another critical issue is to define the correct information to be shared for decision making. Of course, it is easier to say than to implement this in practice. However, the philosophy behind is intuitive.
4. Information sharing is in fact not the only solution. The performance of the adaptive coordination mechanism with quantity flexibility (i.e. the one in Section 6) is not worse than the one with information sharing (i.e. NEG1 and NEG2 in Section 5) subject to the same flexibility. Again, considering

the investment to achieve information sharing, the adaptive coordination mechanism or even the flexible coordination mechanism (i.e. the one in Section 4) would be a more feasible and economic solution.

The research findings can be strengthened in the future by employing more complex supply chain structures for testing. More sources of uncertainties could be added in the system for analysis. For example, unexpected events (e.g. supply interruption) can be modelled as another source of uncertainty in order to verify the research hypothesis regarding flexibility, information sharing, and adaptability in this paper under different scenarios. As a matter of fact, this simulation study is just a piece of proof-of-concept. It is worthwhile to use real data which can be obtained in real cases to verify the achieved simulation results as a future work.

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Manufacturing the Future

Edited by Vedran Kordic, Aleksandar Lazinica and Munir Merdan

ISBN 3-86611-198-3
Hard cover, 908 pages
Publisher Pro Literatur Verlag, Germany / ARS, Austria
Published online 01, July, 2006
Published in print edition July, 2006

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