Using Postponement as a Rescheduling Strategy in the Supply Chain Management under Uncertain Demand Environment

Yahong ZHENG, Khaled MESGHOUNI

Abstract—**Addressing demand uncertainty is a research focus in supply chain management in recent years. In this paper, a new postponement strategy is applied. Postponement has been appreciated recently, especially in the manufacturing period of realizing mass customization. It has also been much used to respond to the demand uncertainty and usually considered in the planning period. However, the decision role of postponement in the supplying process was little focused. It seems simple to utilize the intuitive concept of postponement to deal with demand uncertainty, but in effect there are so many factors and problems needing to be considered that the likely simple utilization becomes rather complex. In order to execute postponement, the strategy used in this paper relies much on the cooperation among the supply chain members. Based on the assumption of ideal cooperation, a linear programming model is established and demonstrated feasible and optimal in the supply chain scheduling under an uncertain demand environment, using postponement as rescheduling strategy.**

Index Terms—**demand uncertainty, postponement, demand-supply subsystem, rescheduling.**

I. Introduction

ALTHOUGH uncertainties in supply chain management have been concerned by many researchers and practitioners, there are still many questions waiting to be dealt with. The uncertainties occur in demand, supply, lead time, manufacturing, etc. In this paper, we will focus on the uncertainties in demand, which is prevalent in supply chain and has become a popular point of research.

A. Uncertainties in demands

Uncertainty in demand refers mainly oscillations and surges of demand. Because the market is dynamic, uncertainty is an essential character of demand. The primary cause of the uncertainty in the demand is customer. Their necessaries, desire and anticipation of consummation, value of consuming, tendency, belief in the production, as well as the degree of infection between consumers could all influence the quantity of consummation. Another important factor influencing demand is the outer environment, such as the policy, assurance, advertisement, accuracy of searching information, production and its life cycle and so on.

Uncertainties in demand influence easily the inventory level of upstream enterprises of supply chain, such as supplier of raw materials,manufacturer, retailer, and so on.Because of the demand uncertainty and inaccurate and asymmetric information, there is a very universal phenomenon called ”Bullwhip Effect”. The subsequence of ”Bullwhip Effect” have been already discussed a lot.

As dealing with uncertainties in demand is so important, many people have considered it in the supply chain management. In the immense literatures, the strategies of robustness and postponement have become hot in these years. Someone have tried to form a robust supply chain to make it immune to the uncertainties of demand. However, most of them is just a super idea and hard to realize(M. Barad et al. (2003) [8],Patricia M. Swafford et al. (2008) [9], Christopher S. Tang (2006) [5]). As we known, the approaches above are not universal to all supply chain, they are only applied in a given case and environment. What we want to develop a general approach that can be applied to most of the practical cases of supply chain management. And the most obvious detect, or the key technical issue of the robust system, is definition of previous contingent. The robustness of system depends on the number of the previous contingent and the method treating it. However, the large scale of the prediction will bring expensive budget and cost to the system. As to this point, the strategy of postponement can work well.

B. Strategy of postponement

Originally, postponement is known as late customization or delayed product differentiation, which was first discussed by W. Alderson (1957) [2]. Since then, postponement strategy has been applied in many industries. The postponement strategy can bring benefits to the enterprise, such as the reduced inventory, the pooling risk, the accurate forecast. However, the disadvantages also exist, for example, the high cost of the designing and manufacturing of common components,cost of reconfiguration of the supply chain structure. Therefore, the postponement is not suitable to all situations(Yu-Ying Huang and Shyh-Jane Li(2008)[14],Q.L.Zen et al. (2006) [10]). Although postponement is more used by the suppliers, it is also used by the demanders(Chunyang Tong (2010) [6]).

Many factors can influence the effects of the postponement strategy, the products price, the cost of each stage of the supply chain, the packaging, the assembling, the inventory cost, the service-level, etc.(Shihua Ma et al. (2002) [12]). Gregory A. Graman (2010) [7] proposed a partial-postponement decision cost model and demonstrated its application in determining the levels of finished-goods inventory and postponement capacity. Q.L.Zen et al. (2006) [10] developed a systematic approach to determine the optimal timing for staged order

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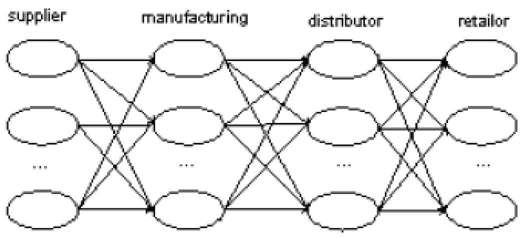

Fig. 1. Normal supply chain structure in the manufacturing industry

commitment, with categorizing attributes and aggregation of processes to reduce the complexity. Postponement has been proved an effective method to treat demand uncertainty(Viswanath Cvsa and Stephen M. Gilbert(2002)[13], Aviv Y and Federgruen A (1998) [4]), as well as the "partial" or "tailored" postponement(Gregory A. Graman (2010) [7]).

Although "postponement "is similar to "delay", it is necessary to distinguish the difference between them. In fact, the term "delay" is always regarded detrimental, especially that in the production and the delay in the transportation. It is a type of uncertainty in supply chain. Here, postponement is a subjective strategy, rather than an objective delay phenomenon in the supply chain process. In the literatures viewed, the postponement used in managing the demands in the period of supplying is much fewer than that in the manufacturing process. The most similar one to our work is the research of Ananth V. Iyer et al. (2003) [1]. He analyzed demand postponement as a strategy to handle demand surges and showed that postponement strategy may lead to reduced investment in initial capacity. But it limited the model in single period of postponement demands. In our work, based on the model of him, we considered the practical condition that including both the regular and postponed demand.

II. Problem Statement

In our work, we propose an intuitive and rather simple approach to cope with the uncertainties in demand, the postponement in supplying process. It disregards to the uncertain demand in our strategy. We respond to the demand surges after they occur. What the supplier should do before the demand unfolds is keeping the normal safe inventory level and negotiating a cooperation between them. Our approach is feasible in an absolute cooperative environment, from the standpoint of the whole supply chain.

Our esprit is that we do not concern the demand distribution or the prior planning process. We focus only on the rescheduling of the supply chain in a simplified supply-demand subsystem described in Fig 2.

Through the process of structure simplification, the objective of research of the complicated supply chain network is turning to the single sub-system of supply chain. There is only one level of demand-supply relation in the sub-system. Our main idea is when the demand occurs, according to the total inventory of all the suppliers, we distribute the equal quantity of demand to certain suppliers. When the uncertainty has realized, the demand D_i is deterministic. And the question is how to decide the quantity of each demander. β is given to represent the ratio of the demand postponed, thereby $1-\beta$ is the part of demands satisfied

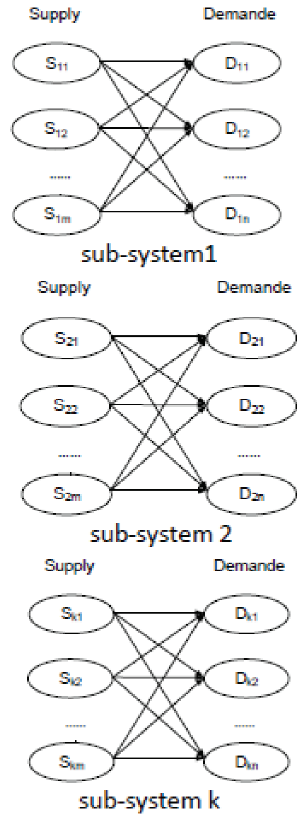

Fig. 2. Simplified supply chain structure

in regular period, α_{ij} is set to describe the ratio of each demand i satisfied by supplier j in regular period, with stocks. This step is called scheduling process. The next step is to complete the unsatisfied demand, i.e. the postponed part β, with β_{ij} to describe the ratio of demand i satisfied by supplier j in postponement period. We call this step a rescheduling process of the sub supply chain system. At last, we reschedule the supply chain hierarchically, from the resource of the demand, i.e. the final market to the end of materials, iterating the following program, as in Fig 2, using three iterations.

The iterating procedure of scheduling is described as follows:

Resumptively, our strategy of postponement is executed in two stages:

i). determine the optimal fraction of total postponed demand β;

ii).determine the optimal fraction α_{ij} for each supply-demand relation in the regular period.

iii). determine the optimal fraction β_{ij} for each supply-demand relation in the postponement period.

Here, we also consider that the supplier reimburses the demander a predetermined unit postponement cost c_3. And we assume that the compensation is equivalent to all demanders.

The nomenclature is given in Appendix A.

III. Optimal fraction of total postponed demand β

The fraction of demand to satisfy in the regular period is $(1-\beta)$.

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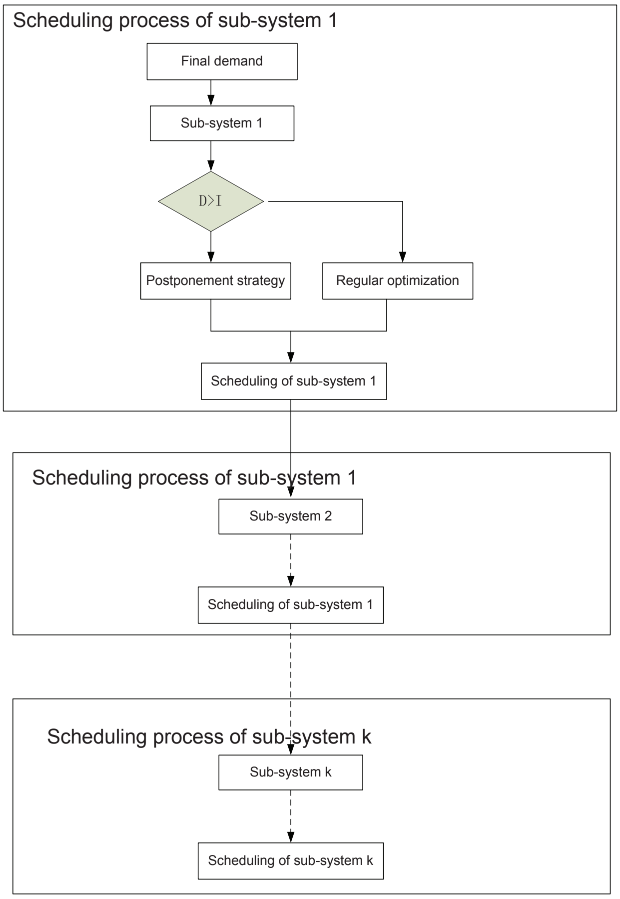

Fig. 3. Procedure of the scheduling with the postponement strategy

The capacity of the suppliers (mainly signifying the inventory) must be able to satisfy the demand in the regular period, the $(1-\beta)$ part demand. The capacity of the suppliers is mainly the inventory level. We have assumed that the information of suppliers is already known. The inventory level is constant. So we can get an inventory constraint as follows:

$$(1-\beta)\sum_{i=1}^{n} D_i \leq \sum_{j=1}^{m} k_j \tag{1}$$

And in the period of postponement, the demand is satisfied by manufacturing. According to the manufacturing capacity (supply capacity) of the suppliers, we can get the manufacturing constraint:

$$\beta\sum_{i=1}^{n} D_i \leq \sum_{j=1}^{m} s_j t_j \tag{2}$$

In the inequality above, t_j must be controlled in the allowable postponing time T, which includes manufacturing time t_j and transporting time p_j.

$$K = \sum_{j=1}^{m} k_j \tag{3}$$

$$T = t_j + p_j \tag{4}$$

$$D = \sum_{i=1}^{n} D_i \tag{5}$$

Although t_j is a variable waiting to design, with the purpose of simplifying the definition of β, in reality, according to the allowable postponement time, we can choose an expected value constant t, we note,

$$S = t\sum_{j=1}^{m} s_j \tag{6}$$

Then we obtain that

$$1 - \frac{K}{D} \leq \beta \leq \frac{S}{D} \tag{7}$$

In order to reduce the complexity of calculating, we assume that the unit cost of conversation c_1, the unit cost of manufacturing c_2 and the unit compensation for postponing to demanders are identical to every supplier. And the allowable lead time of delivery T is also equivalent.

The expected cost of the supplier in the supplying process is

$$\begin{aligned} V_1(\beta) = {} & c_1\sum_{j=1}^{m} k_j + c_2\beta\sum_{i=1}^{n} D_i + c_3\beta\sum_{i=1}^{n} D_i + \\ & c_4(\sum_{j=1}^{m} k_j - (1-\beta)\sum_{i=1}^{n} D_i) \\ & = c_1K + \beta D(c_2 + c_3 + c_4) + c_4(K - D) \end{aligned} \tag{8}$$

The first term of the above formulation is the cost of the production of inventory; the second term is the new manufacturing cost for satisfying the postponed demands, including all the costs of manufacturing,cost of material, processing, assembly, etc.; the third part is compensation for postponing paid to demanders; the last part is conservation costs. As the transporting cost is related to the single amount of delivery and the calculation is rather complicated, in this period of calculation of β, we do not consider the transporting cost.

From the function of cost, we find that the cost is proportional to the postponement fraction β.

So the optimal value of β is:

$$\beta^* = 1 - \frac{K}{D} \tag{9}$$

And the optimal expected cost is

$$\begin{aligned} V_1^*(\beta) &= c_1K + (D-K)(c_2 + c_3 + c_4) \\ &+ c_4(K - D) = c_1K + (D-K)(c_2 + c_3) \end{aligned} \tag{10}$$

IV. Optimal fraction of supplying to each supplier

After the total postponement fraction has been determined, the optimal fraction to each supplier in the regular period α_{ij} and that in the postponement period β_{ij} can be calculated. Both the two calculations will be firstly discussed separately, and then we integrate them to execute the calculation of optimization.

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A. Optimal fraction of supplying to each supplier in regular period, α_{ij}

In the relationship of present enterprise, the long-term cooperation is appreciated. So in reality, most of time, the demand is send to the familiar customers. In our work, we have supposed a complete ideal situation of the cooperation among the enterprizes in the same supply chain (SC). The demand is allocated just according to the objective of minimization of cost and the maximization of service level.

As the cost of production, conservation, compensation for postponing paid to demanders is concerned with total postponement fraction, here we only have to consider the distance and cost of transportation with α_{ij}. We should also consider the practical distance and cost from the supplier to the relative demander. Let r_{ij} denote the distance between the supplier and the demander.

The cost of transporting concerns mainly with the distance of delivery:

$$\min V_2(\alpha_{ij}) = \min[c_5 \sum_{i=1}^{n}\sum_{j=1}^{m} r_{ij} \cdot D_i \cdot \alpha_{ij}] \tag{11}$$

The unit cost of transporting c_5 is probably inversely proportional to the amount of delivery. So, for the sake of low cost, the suppliers deliver production only when they have a reasonable amount and transporting cost. For example, the threshold of the amount is m, when the quantity of delivery qm, they do not want to deliver. So there is a delivery amount constraint:

$$D_i\alpha_{ij} \geq m \tag{12}$$

And the service level refers mainly to the satisfaction of the demand, which is already included in the following demand constraint:

$$\sum_{i=1}^{n}\sum_{j=1}^{m} D_i\alpha_{ij} = (1-\beta)\sum_{i=1}^{n} D_i \tag{13}$$

The demand satisfied in the regular period is by the inventory production, that is

$$\sum_{i=1}^{n} D_i\alpha_{ij} \leq k_j \tag{14}$$

The natural attribution of the rate of distribution is:

$$0 \leq \alpha_{ij} \leq 1 \tag{15}$$

From the formulations above, we can get the fraction of demand postponement allocated to each supplier.

B. Optimal fraction of postponement to each supplier in the postponement period, β_{ij}

After the total postponement fraction and the optimal fraction of supplying of each supplier in the regular period have been determined, the optimal fraction of each supplier in the postponement period can be calculated.Different from calculating the total cost of postponement, the allocation of postponement is more complicated. Here, like the allocation of demand in regular period, the cost of transporting concerns mainly with the distance of delivery:

$$\min V_3(\beta_{ij}) = \min[c_5 \sum_{i=1}^{n}\sum_{j=1}^{m} r_{ij} \cdot D_i \cdot \beta_{ij}] \tag{16}$$

The transporting amount constraint:

$$D_i\beta_{ij} \geq m \tag{17}$$

The total postponed demand distributed to each supplier, we get:

$$\sum_{i=1}^{n}\sum_{j=1}^{m} D_i\beta_{ij} = \beta^* \sum_{i=1}^{n} D_i \tag{18}$$

The postponed demand is satisfied by the new supply capacity (from the nodes upstream or manufacturing itself):

$$\sum_{i=1}^{n} D_i\beta_{ij} \leq t \cdot s_j \tag{19}$$

The demand constraints are:

$$\sum_{i=1}^{n} \beta_{ij} = 1 - \sum_{i=1}^{n} \alpha_{ij} \tag{20}$$

And the natural attribution of the rate of distribution is:

$$0 \leq \beta_{ij} \leq 1 \tag{21}$$

From the calculation of the formulations above, we can get the fraction of demand postponement allocated to each supplier.

C. Integrated calculation

If we use the separated calculation, the constraints are not considered simultaneously, and then we may get some solutions infeasible. Therefore, we integrate the formulations in the two periods and solve them simultaneously.

We get the optimizations to be solved as follows:

$$\begin{aligned}\min V_2(\alpha_{ij}) = \min[c_5 \sum_{i=1}^{n}\sum_{j=1}^{m} r_{ij} \cdot D_i \cdot \alpha_{ij} \\ + c_5 \sum_{i=1}^{n}\sum_{j=1}^{m} r_{ij} \cdot D_i \cdot \beta_{ij}]\end{aligned} \tag{22}$$

All the constraints (12)-(15), (17)-(21) in the two periods must be satisfied here.

V. Numerical results

To demonstrate the feasibility and effectiveness of our approach dealing with uncertainties in demand, we apply it to the example of Alev Taskin Gumus et al. [3] (2009).

A. The model description from the original SC network

The case used in [3] is a SC network design presented for a reputable multinational company in alcohol free beverage sector. The existing SC ,the cost and capacity data from existing SC network refer to [3].

In this model, 2 factories (F_1, F_2), 3 warehouses (W_1, W_2, W_3) and 6 distributors (D_1, D_2, D_3, D_4, D_5, D_6) are selected from the company's system in order to explain the existing design of the network, and considering that the product flow is followed by only one product of the company.The question to solve is to decide and design the best SC network to satisfy the demand, simultaneously to minimize the supply cost.

Firstly, we simplify the SC network as two sub-systems as in Fig 4.

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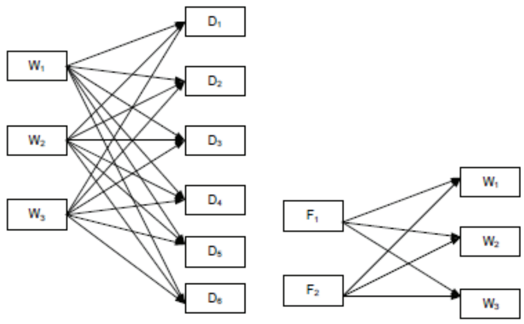

Fig. 4. a) Sub-system1 b) Sub-system 2

Besides applied mainly in the case where the inventories of suppliers do not satisfy current demands, our approach is also an effective scheduling method in the allocation of demand in the case where the stock is enough to satisfy demands.

In order to use our methodology, we adjust the parameters:

The concept of transportation distances are replaced by the different unit transportation costs. Therefore,$c_5 = 1$, r_{ij} refers to the transportation costs.

As we do not know exactly the physical inventory, we assume that the inventory is equal to the warehouse capacity. Thus, corresponding the data of the capacities of the factories and warehouses to our model, in sub-system 1, $k_1 = 3,785,630$,$k_2 = 1,564,479$,$k_3 = 346,094$,$K = \sum_{j=1}^{3} k_j = 5696203$; In sub-system 2, $k_1 = 3,011,970$,$k_2 = 1,298,716$,$\sum_{j=1}^{2} k_j = 4310686$

Different from the work in [3], we do not need to estimate demand. We use the estimation of demands as the real occuring demands. That is, in sub-system 1, $D = \sum_{i=1}^{6} D_i = 394915$; after we finished the calculation of sub-system 1, using the result, we can calculate for sub-system 2. In this case,$D < K$, therefore, we need not use the postponement strategy for rescheduling the SC network, that is, $\beta = 0$. The optimization method is enough for the scheduling in this case.

B. Results of calculation using our approach for the situation with estimated demand

The problem waiting to be solved is a linear programming problem. We use LINDO 6.1 to resolve it.

In order to simplify the execution of calculation, we ignore the constraint of transporting amount.

Calculation results for sub-system1 as referred to Table I. Allocation of the demands of distributors to each warehouse is specified in Table II. As calculated from the results in sub-system 1, we get the demands in sub-system 2:$D = \sum_{D}^{i} = 394915$,$D < K$. there is still no need to use the postponement strategy. $\beta = 0$. Calculation results for sub-system 2 is figured in Table III; the Allocation of the demands of warehouses to each factory seen in Table IV.

In the uncertain demand environment, where $D > K$, the postponement strategy is just appropriate to cope with the unexpected demand. We can get similar calculation results as the ones above.

TABLE I
CALCULATION RESULTS FOR SUB-SYSTEM1 IN THE CASE WITH ESTIMATED DEMAND

Variable	Value	Variable	Value
α_{11}	0.000000	α_{41}	0.000000
α_{12}	0.000000	α_{42}	0.000000
α_{13}	1.000000	α_{43}	1.000000
α_{21}	0.000000	α_{51}	0.000000
α_{22}	0.880848	α_{52}	0.000000
α_{23}	0.119152	α_{53}	1.000000
α_{31}	0.000000	α_{61}	0.000000
α_{32}	0.000000	α_{62}	0.000000
α_{33}	1.000000	α_{63}	1.000000
Objective value	58605.25		

TABLE II
ALLOCATION OF THE DEMANDS OF DISTRIBUTORS TO EACH WAREHOUSE IN THE CASE WITH ESTIMATED DEMAND

Warehouses	Distributors					
	D_1	D_2	D_3	D_4	D_5	D_6
W_1	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
W_2	0.000000	0.880848	0.000000	0.000000	0.000000	0.000000
W_3	1.000000	0.119152	1.000000	1.000000	1.000000	1.000000

TABLE III
CALCULATION RESULTS FOR SUB-SYSTEM2 IN THE CASE WITH ESTIMATED DEMAND

Variable	Value
α_{11}	0.000000
α_{12}	0.000000
α_{21}	1.000000
α_{22}	0.000000
α_{31}	0.880848
α_{32}	0.119152
Objective value	58605.25

TABLE IV
ALLOCATION OF THE DEMANDS OF WAREHOUSES TO EACH FACTORY IN THE CASE WITH ESTIMATED DEMAND

Factories	Warehouses		
	W_1	W_2	W_3
F_1	0.000000	0.034962	1.000000
F_2	0.000000	0.965038	0.000000

C. Discussions

According to the result of ANN simulation in [3], the first and second factories, and the first and second warehouses are open, but the third warehouse is closed. On the other hand analytical method gives a solution in which all the factories and the warehouses are open. While ANN simulation finds 182,021 dollars for the minimum cost, analytical method's result is 167,231 dollars. Dealing with the same quantity of demands, our results show the optimal scheduling is that, the first and second factories, the second and third warehouses are open, while the first warehouse is not uses. The minimum cost is 196833.45 dollars. It is not as good as compared to the results in [3], however, the limit of their methods is the constraint that the capacity of the warehouses should be equal or more than the demand of the distributor. This is just what we want to deal with, the case where the demand is beyond

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the capacity of the inventory capacity.

Moreover, another advantage of our method is that it can quickly get the optimal replenishment strategy after the emptying of stocks which is used to satisfy the demands in regular period. There are usually several strategies to choose, we can execute our postponement strategy for different cases separately, and then we compare them to find the one with least cost as the optimal proposal.

VI. Conclusions and Future Research

In this paper, we have proposed a postponement strategy in the scheduling of supply chain network to cope with uncertainties in demand, based on the hierarchal sub-system of the supply chain network and the ideal cooperation of the agents in supply chain. A linear programming model is employed to get the optimal allocation of the supplier to the demand, with the minimization of the supply cost as the objective. It is demonstrated feasible and powerful in the scheduling of supply chain in practical example. We found that, even in the cases where the inventory is enough to satisfy the demand, our optimization model is also appropriate. The postponement strategy is only needed when the total invetntory cannot satisfy the total demand. We have compared the results of treating the same demands to the results in [3]. It is completely reasonable.

Inevitably, some drawbacks and limits exist in our research. In fact, we did not consider the physical position relationship of the members of supply chain. In that case, we need more data of the distribution of all the agents of the supply chain, which will make the scheduling more complicated. In our future study, we can take it into account to complete the scheduling process. As to the products in the logistics, we only have treated the flow of finished products. The treatment of materials and parts will be more interesting and complex. Another drawback is in the calculation. In fact, in order to get the parameters needed in calculation of linear programming in LINDO 6.1, we have done a lot of preparing work by hands, using programming in software will bring much convenience. As well, the usage of the linear programming is limited in small large of calculation. For larger scale of calculation, a heuristic algorithm will be more appropriate.

Appendix A
List of Notation

β- Optimal fraction of total postponed demand

α_{ij} -ratio of demand i satisfied by supplier j in regular period

β_{ij} -ratio of demand$i$satisfied by supplier j in postponement period

For sub-system k,

D_i - demand of i^{th} demander

D- total demand

s_j - supply capacity of j^{th} supplier in the postponement period

t_j -manufacturing time for supply of j^{th} supplier in the postponement period

t-the expected manufacturing time constant

T-allowable postponing time

p_j -transportation time of j^{th} supplier in the postponement period

S - Total supplying capacity of supplier in the postponement period

I_j- inventory level of the j^{th} supplier

k_j -the inventory of j^{th} supplier

I- total inventory

c_1- the unit cost of the production of inventory

c_2 - unit cost of new manufacturing cost for satisfying the postponed demand

c_3 - unit cost of compensation paid by the suppliers to demanders for postponement

c_4- unit cost of conservation between the two delivery times

c_5- unit cost of transporting

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