SUPPLY CHAIN MANAGEMENT SYSTEM FOR CONSTRUCTION MATERIAL PLANNING

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Abstract: This study relies on integrated inventory theory which merges with the supply chain concept and aims at the steel bar material of precast factory's two-echelon supply chain system. In order to consider the variable demand rate, unfixed supply time, unfixed supply frequency and unfixed supply quantity, this study builds a strategic model that minimizes the total inventory cost of all participators. Based on the established model, the material's supply plan comes into existence, which takes into consideration the time and quantity of material supply, and the starting time of the supplier's production. It is expected that the study result can be useful reference for participators to deal with the material supply in a more efficient way.

Keywords: supply chain, integrated inventory, precast, material planning

1. INTRODUCTION

With characteristics of construction industry such as high construction cost, long duration, and complicated participators, it is very difficult to plan and deal with the managerial affairs in a construction project. As to materials, which consist large portion of construction cost, thus have the same problem. Without a complete plan, it may cause many obstacles in the supply procedure, for example delays in the schedule or wastes of other resources when some materials are supplied too late. And when some materials are supplied too early, it will also probably raise the inventory cost on carry, storage, overdue and insurance. In the construction industry, the planning and management of material supply are usually handled roughly with past experience and limited information. It lacks for some more systematic methods to increase the decision benefit.

However, in the other industries, many inventory theories have been well developed and matured to avoid supplying materials inappropriately. Some of these theories have already integrated the concept of supply chain management. In the opinion, all participators striding across boundaries in the transaction have been considered as a whole chain system. Instead of the individual optimum, the entirety optimum is the basis of policy making.

The traditional inventory model is based on the optimization for individual enterprise system. Relatively, by mutually coordinating and adjusting working processes to improve global benefits, the integrated inventory decision-making is focused on all partners of supply chain from upstream to downstream to minimize the total inventory cost.
From the theoretical development, Monahan (1984) fist proposed an economic order quantity model to take a lot-to-lot procuring strategy. The quantity discount pricing model will increase vender's profits. Lee and Rosenblatt and Banerjee（1986）expended and promoted Monhahan's model to enhance the vendee's order quantity by optimal discount pricing strategy. Further, Goyal（1988）, Srinivasan (1992), Aderohunmu et al（1995）has proposed near idea and deeper description to improve the effectiveness of inventory management and reduce cost by business mutual corporation and pre-defined coordination. Obviously, the strategic alliance of specific supply chain will be highly relied on a rational mechanism which will benefit all the partnering members.

The integrated inventory model of this study is mainly developed for the precast factory and upper supplier of steel bar to be possible to make a globally beneficial supply planning. Therefore, this preliminary study is limited under the condition as follows :

- pure inventory system (not including producing and distributing system)
- simple two hierarchy system
- many buyer to single supplier type
- decision making by minimum total cost
- single material consideration of steel bar
- variable material demand rate
- flexible supply times and quantities in certain period
- not allowable for material deficiency

2. ESTABLISHMENT OF THE MODEL

In the supply planning of integrated inventory model, the difference quantity between buyer's demand and supply can be regarded as the buyer's inventory level. Relatively, the same designation also fits the supplier side. By checking the inventory level of both sides and coping with individual cost requirements, the integrated inventory cost can be calculated. The objective function of this model lies on the total inventory cost combination of all supply chain participants. For purpose of simplicity, an illustration of developing the model is depicted as Figure 1 in which the specific buyer *m* is assigned to need three times of material supply in a certain time period. equations. The relative symbols used in this Figure can be referred at the end of this paper Notation.

2.1 Inventory cost for buyers

This present model considers only the item of inventory keeping cost for buyers, not including the other costs such as ordering, delivering and shortage cost. The inventory cost for buyers can be derived as following steps from equation (1) to (8).

Step 1. The demand area for buyer *m* at cycle *i:*

$$AreaD_{m,i} = Area1 + Area2 + Area3 \qquad (1)$$

where

$$AreaD_{m,i} = \sum_{k=1}^{E_{m,i,k}} \frac{1}{2} \left\{ \begin{array}{l} 2\left[\sum_{s=1}^{k} (DCP_{m,i,s} - DCP_{m,i,s-1}) DR_{m,i,s-1} \right] + \\ (DCP_{m,i,k+1} - DCP_{m,i,k}) DR_{m,i,k} \end{array} \right\} \cdot (DCP_{m,i,k+1} - DCP_{m,i,k})$$

$$If\ k = E_{m,i,k}\text{，}Then\ DCP_{m,i,k+1} = CSP_{i+1};$$
$$ps\ DCP_{m,i,0} = DR_{m,i,0} = 0$$

(2)

Step 2. The supply area fro buyer *m* at cycle *i*:

$$AreaS_{m,i} = SQ_{m,i,1} \cdot (SP_{m,i,2} - SP_{m,i,1}) + (SQ_{m,i,1} + SQ_{m,i,2}) \cdot (SP_{m,i,3} - SP_{m,i,2}) + (SQ_{m,i,1} + SQ_{m,i,2} + SQ_{m,i,3}) \cdot (CSP_{i+1} - SP_{m,i,3}) \qquad (3)$$

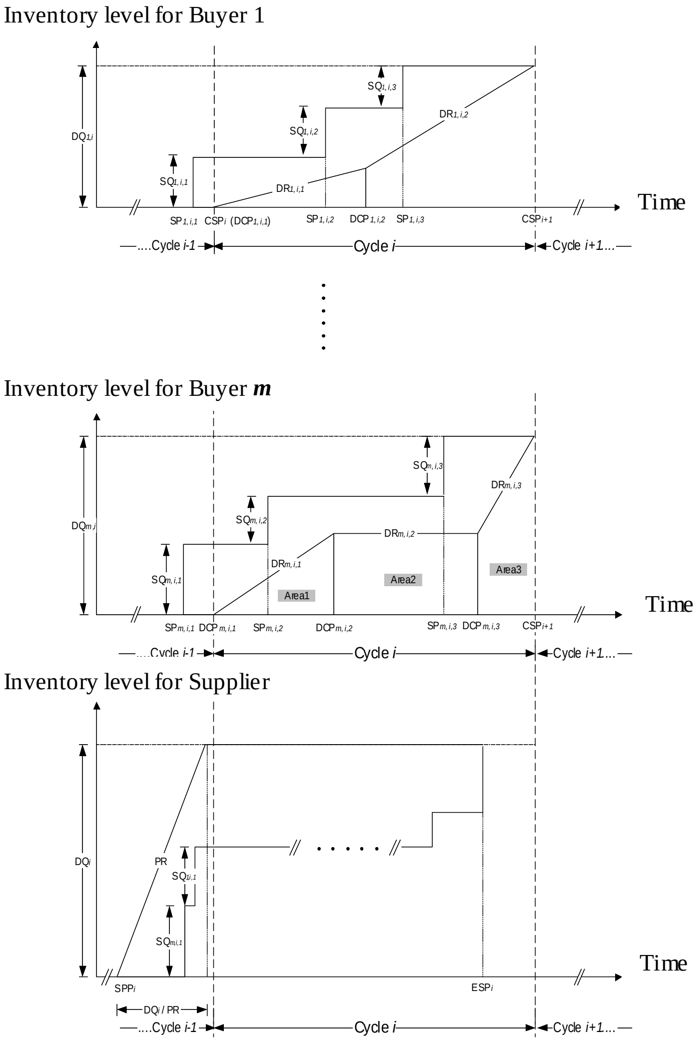

Figure 1. Expression of inventory level for the buyers and supplier

where

$$AreaS_{m,i} = \sum_{j=1}^{E_{m,i,j}} \left[\left(\sum_{s=1}^{j} SQ_{m,i,s} \right) \cdot (SP_{m,i,j+1} - SP_{m,i,j}) \right]$$

$$If\ \ j = E_{m,i,j}\text{，}\ Then\ SP_{m,i,j+1} = CSP_{i+1} \qquad (4)$$

Step 3. The inventory area for buyer *m* at cycle *i* is shown in Figure1with bold lines circled:

$$AreaI_{m,i} = AreaS_{m,i} - AreaD_{m,i} \qquad (5)$$

Step 4. The keeping cost for buyer *m* at cycle *i:*

$$IC_{vm,i} = AreaI_{m,i} \times IUC_{vm} \qquad (6)$$

Step 5.The total cost for buyer m is the summation of all keeping cost at every cycles:

$$TC_{vm} = \sum_{i=1}^{E_i} IC_{vm,i}$$
$$= \left\{ \begin{array}{l} \sum_{i=1}^{E_i}\sum_{j=1}^{E_{m,i,j}} \left[\left(\sum_{s=1}^{j} SQ_{m,i,s} \right) \cdot \left(SP_{m,i,j+1} - SP_{m,i,j} \right) \right] - \\ \sum_{i=1}^{E_i}\sum_{k=1}^{E_{m,i,k}} \frac{1}{2} \left\{ \begin{array}{l} 2\left[\sum_{s=1}^{k} \left(DCP_{m,i,s} - DCP_{m,i,s-1} \right) DR_{m,i,s-1} \right] + \\ \left(DCP_{m,i,k+1} - DCP_{m,i,k} \right) DR_{m,i,k} \end{array} \right\} \cdot \left(DCP_{m,i,k+1} - DCP_{m,i,k} \right) \end{array} \right\} \cdot IUC_{vm}$$

$If\ \ k = E_{m,i,k}$ ，$Then\ \ DCP_{m,i,k+1} = CSP_{i+1}$;
$If\ \ j = E_{m,i,j}$ ，$Then\ \ SP_{m,i,j+1} = CSP_{i+1}$;
$ps.\ \ DCP_{m,i,0} = DR_{m,i,0} = 0$

(7)

Step 6. All buyers inventory cost can be equated:

$$TC_v = \sum_{m=1}^{E_v} TC_{vm}$$
$$= \sum_{m=1}^{E_v} \left\{ \begin{array}{l} \sum_{i=1}^{E_i}\sum_{j=1}^{E_{m,i,j}} \left[\left(\sum_{s=1}^{j} SQ_{m,i,s} \right) \cdot \left(SP_{m,i,j+1} - SP_{m,i,j} \right) \right] - \\ \sum_{i=1}^{E_i}\sum_{k=1}^{E_{m,i,k}} \frac{1}{2} \left\{ \begin{array}{l} 2\left[\sum_{s=1}^{k} \left(DCP_{m,i,s} - DCP_{m,i,s-1} \right) DR_{m,i,s-1} \right] + \\ \left(DCP_{m,i,k+1} - DCP_{m,i,k} \right) DR_{m,i,k} \end{array} \right\} \cdot \left(DCP_{m,i,k+1} - DCP_{m,i,k} \right) \end{array} \right\} \cdot IUC_{vm}$$

$If\ \ k = E_{m,i,k}$ ，$Then\ \ DCP_{m,i,k+1} = CSP_{i+1}$;
$If\ \ j = E_{m,i,j}$ ，$Then\ \ SP_{m,i,j+1} = CSP_{i+1}$;
$ps.\ \ DCP_{m,i,0} = DR_{m,i,0} = 0$;

(8)

2.2 Inventory cost for supplier

Similarly, the total inventory cost for supplier is equal to the all keeping cost in every cycle. It is described by the following detailed steps.

Step 1. The producing area for supplier at cycle i:

Also, in Figure 1 the trapezoid area circled by producing lines can be calculated as

$$AreaP_i = \frac{1}{2}\left[\left(ESP_i - SPP_i - \frac{\sum_{m=1}^{E_v} DQ_{m,i}}{PR} \right) + \left(ESP_i - SPP_i \right) \right] \cdot \sum_{m=1}^{E_v} DQ_{m,i}$$

(10)

(9)

Step 2. Supplier’s Supplement area at cycle i is the summation of all provision to buyers（*AreaSm,i*）

$$AreaS_{s,i} = \sum_{m=1}^{E_v} AreaS_{m,i} \qquad (10)$$

Step 3. The inventory area for supplier at cycle i is circled by bold lines in Figure1:

$$AreaI_{s,i} = AreaP_i - AreaS_{s,i} \qquad (11)$$

Step 4. The inventory keeping cost for supplier at cycle i :

$$IC_{si} = AreaI_{s,i} \times IUC_s \qquad (12)$$

Step 5. The total inventory cost for supplier:

$$TC_s = \sum_{i=1}^{E_i} IC_{si}$$
$$= \sum_{i=1}^{E_i} \left\{ \begin{array}{l} \frac{1}{2}\left[\left(ESP_i - SPP_i - \frac{\sum_{m=1}^{E_v} DQ_{m,i}}{PR} \right) + \left(ESP_i - SPP_i \right) \right] \cdot \sum_{m=1}^{E_v} DQ_{m,i} - \\ \sum_{m=1}^{E_v}\sum_{j=1}^{E_{m,i,j}} \left[\left(\sum_{s=1}^{j} SQ_{m,i,s} \right) \cdot \left(SP_{m,i,j+1} - SP_{m,i,j} \right) \right] \end{array} \right\} \cdot IUC_s$$

$If\ \ j = E_{m,i,j}$ ，$Then\ SP_{m,i,j+1} = CSP_{i+1}$;

(13)

2.3 Joint total inventory cost

According to equation (8) and (13), the joint inventory cost cab be derived as following:

$$JTC = TC_v + TC_s$$
$$= \sum_{m=1}^{E_v} \left\{ \begin{array}{l} \sum_{i=1}^{E_i}\sum_{j=1}^{E_{m,i,j}} \left[\left(\sum_{s=1}^{j} SQ_{m,i,s} \right) \cdot \left(SP_{m,i,j+1} - SP_{m,i,j} \right) \right] - \\ \sum_{i=1}^{E_i}\sum_{k=1}^{E_{m,i,k}} \frac{1}{2} \left\{ \begin{array}{l} 2\left[\sum_{s=1}^{k} \left(DCP_{m,i,s} - DCP_{m,i,s-1} \right) DR_{m,i,s-1} \right] + \\ \left(DCP_{m,i,k+1} - DCP_{m,i,k} \right) DR_{m,i,k} \end{array} \right\} \cdot \left(DCP_{m,i,k+1} - DCP_{m,i,k} \right) \end{array} \right\} \cdot IUC_{vm} +$$
$$\sum_{i=1}^{E_i} \left\{ \begin{array}{l} \frac{1}{2}\left[\left(ESP_i - SPP_i - \frac{\sum_{m=1}^{E_v} DQ_{m,i}}{PR} \right) + \left(ESP_i - SPP_i \right) \right] \cdot \sum_{m=1}^{E_v} DQ_{m,i} - \\ \sum_{m=1}^{E_v}\sum_{j=1}^{E_{m,i,j}} \left[\left(\sum_{s=1}^{j} SQ_{m,i,s} \right) \cdot \left(SP_{m,i,j+1} - SP_{m,i,j} \right) \right] \end{array} \right\} \cdot IUC_s$$

$If\ \ k = E_{m,i,k}$ ，$Then\ DCP_{m,i,k+1} = CSP_{i+1}$;
$If\ \ j = E_{m,i,j}$ ，$Then\ SP_{m,i,j+1} = CSP_{i+1}$;
$ps\ \ DCP_{m,i,0} = DR_{m,i,0} = 0$

(14)

2.4 Constraints for integrated inventory model

Based on the above model foundation, there are several constraints raised to make it possible for practical application.

- Supply time need to start before the required duration of demand
- There is a constraint of total supply numbers at a cycle
- There is a quantitative limit for a single supply.
- The cumulative demand quantity for buyers is not greater than total supply at any time.
- Total supply quantity for the supplier is always less than the cumulative producing quantity at

any time.

3 ILLUSTRATIVE EXAMPLE

To demonstrate the effects of the proposed model and corresponding supply plan, an illustrative example is presented in this section and the sensibility test is conducted as well. In this example of Figure 2, with three major participators, a steel bar supplier provides all demands on steel of a precast factory and Buyer B. And all conditional parameters needed in the model are assigned and shown in Table 1.

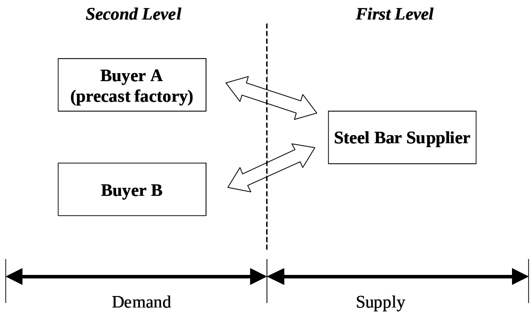

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Figure 2. Illustrative example for a two-echelon supply chain system

Table1. Conditional setting of the example

Common Conditions	Planning material target	D13 Steel bar	
	Planning period range	12 Weeks	
	Period length	2 Weeks	
	No. of period cycle	6	
	Supply time unit	2 Days	
Buyers Condition Setting		Buye A（precast factory）	Buyer B
	Inventory cost (dollar/ton/day)	15	12
	Unit of supply quantity（ton）	10	50
	Minimal supply unit per time	2	8
	Maximal supply unit per time	6	12
	No. of minimal supply per cycle	1	1
	No. of maximal supply per cycle	4	4
	Precedent time before the first supply (day)	1	1
Supplier Conditions	Inventory cost (dollar/ton/day)	10	
	Producing rate（ton/day）	350	
	Minimal precedent time before producing（day）	1	
	Maximal precedent time before producing（day）	2	

3.1 Calculation results

The following Table 2. and Table 3. indicates the distribution of inventory costs allocated at each participator of this example setting and the joint costs under the consideration of minimizing the overall inventory cost, which is the outcome of the integrated inventory model suggested by this research. Figure 3 further shows the prominent effect of the model that all overall costs considering individual minimization are much higher than that of the present model.

Table 2. Comparison of inventory cost among participators

Period cycle	Buyer A		Buyer B		Steel Bar Supplier		Joint Cost（$）
	cost（$）	Percentage on cycle total cost (%)	cost（$）	Percentage on cycle total cost (%)	cost（$）	Percentage on cycle total cost (%)	
1	4725	2.72	51600	29.74	117200	67.54	**173525**
2	2175	2.38	43800	47.99	45300	49.63	**91275**
3	4800	3.18	48000	31.79	98200	65.03	**151000**
4	2250	2.94	37200	48.60	37100	48.47	**76550**
5	4650	3.03	54600	35.63	94000	61.34	**153250**
6	5925	5.71	31200	30.08	66600	64.21	**103725**
sum	24525	3.27	266400	35.55	458400	61.18	***749325***

Table 3. Comparison of total joint inventory cost

Cycle	Total joint cost conducted by the present model（$）	Total joint cost led by buyer A（$）	Total joint cost led by buyer B（$）	Total joint cost led by steel bar supplier（$）
1	173525	220525	210125	193525
2	91275	116275	112175	97175
3	151000	196600	189200	166800
4	76550	101150	99150	80950
5	153250	190450	183750	171350
6	103725	147925	145025	112025
sum	***749325***	***972925***	***939425***	***821825***
Increasing cost percentage compared with the present model (%)		***29.84***	***25.37***	***9.68***

4. SENSITIVITY ANALYSIS

To verify the effect of applying integrated inventory model, several sensitivity tests depending on the variable producing rate of steel bar towards three major model participators are conducted. All testing results reflect the expected inference. Figure 4 further indicates that the cost of steel bar supplier has the highest sensitivity toward the variable producing rate than other participators, but there is not a linear relation between the supply rate and the overall cost. In other words, there exist a supply rate that can also minimize the overall inventory cost.

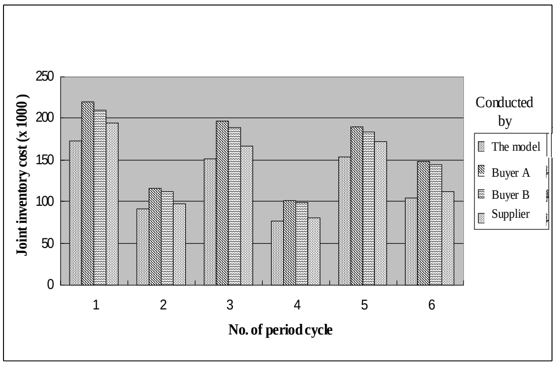

Figure 3. Comparison of total joint inventory cost conducted by different participators

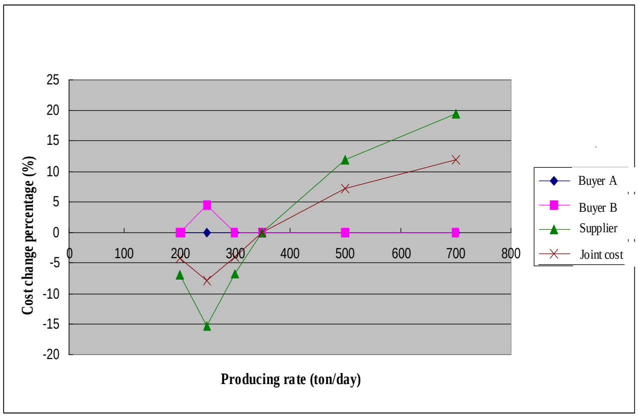

Figure 4. Sensitivity analysis of variable producing rate in the illustrative example

5. CONCLUSIONS

In accordance of the theorem of supply chain that optimizes the whole profits of all participators, this research provides a two-echelon integrated inventory model for steel bar supplier and precast factories with the variable demand rate, unfixed supply time, frequency and quantity. The illustrative example also demonstrates the effectiveness of the model. With the satisfactory outcomes for each case in the example and the result of sensitivity analyses, we can conclude as follows:

1. The present integrated inventory model minimizes the overall inventory cost compared with any inventory models considering individual minimization.

In the example, the overall inventory costs considering any individual minimization are higher than that of integrated inventory model (Minimizing the cost of individual precast factory has a 29.84% higher than the present model of overall integrated viewpoint, while buyer B with 25.37% higher and the steel bar supplier with 9.68% higher) It can be concluded that planning with the cost minimization only for one participator could induce a peak of cost for another, however, which results in a higher overall inventory cost. Although the integrated inventory model cannot guarantee a lowest cost for each participator, its overall cost can rationally reach a minimum. This conclusion complies with the essence of supply chain theorem.

2. Planning centered at the participator with lowest impact on material cost would induce the highest overall inventory cost

According to the figures shown in the example, the inventory cost of the precast factory is much lower than that of Supplier A, and planning centered at the precast factory induce the highest overall inventory cost. The similar result can also be observed in the sensibility test.

3. Planning with higher supply frequency but lower quantity would possibly reduce the overall inventory cost

According to the result of the sensibility test, with the assumption that suppliers can fully meets the demand of the precast factory, planning with higher supply frequency but lower quantity would reduce the overall inventory cost. In other words, a higher supply frequency avoids high holding cost, and thus reduces the overall cost. This reflects the concept of Just In Time inventory management (JIT) discussed and applied in many industries around the world recently. A high supply frequency, however, may also induce other cost, such as production cost, transportation cost, and inspection costs, which results in the increase of the overall cost. Therefore, a more complete inventory model covering the quantity-frequency tradeoff is necessary to take to confirm the minimum of overall cost.

4. There indeed exists a supply rate that minimizes the overall inventory cost

According to the result of the sensibility test, there is not a linear relation between the supply rate and the overall cost. If the supply rate is set as 250 tons per day in the same case (350 tons per day is the default), it turns out a lower overall inventory cost. As a result, there exist a supply rate that can also minimize the overall inventory cost, which can be obtained by applying interpolation in the sensitivity test.

6. FUTURE RECOMMENDATIONS

Due to the real complexity and characteristics of construction industry, it really requires to take many factors into account when enterprises make their material resource planning beyond the study. That is, the scope of consideration would definitely need to enlarge in applying the theorem of supply chain in such plans. This research could be a pilot study of designing a supply chain for the construction industry in Taiwan and thus many improvements of the model and other methodologies used for optimization are necessary to induce. First, the major contradiction of theorem of supply chain lies on the reallocation of the cost saved by the integrated consideration for all participators as a team. The distribution of profits needs to be addressed in the entire planning system according each role and its contribution to the chain. Secondly, time points for billing and parameters such as other cost accounts, the level of inventory, and discount due to lot size, should be included into the inventory model in order to enhance the precision of the prediction. Finally, more effective methodologies to find the optimal solution such as Generic Algorithm (GA) or Neural Network (NN) can be introduced to solve the problem of combination explosion in the real world.

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Notation

i = planning cycle index
j = supply index in a cycle
k = demand index
m = buyer index
SQ =Supply Quantity
SP =Supply Time Point
Ei = the last cycle index for joint planning cycle
Ev = buyer's ordering quantity
Em,i,j = the index for buyer m at cycle i
Em,i,k = the last index for buyer m at cycle i to change demand
CTL =Cycle Time Length
CSP = Cycle Start Point
DR = Demand Rate
DCPm,i,k = Demand Change Point
DQ =Demand Quantity
SPP =Start Produce Point
ESPi = End Supply Point
PR = Produce Rate
IUCvm = Inventory Unit Cost for buyer m
IUCs = Inventory Unit Cost for supplier
ICvm,i = Inventory Cost for buyer m at cycle i
ICsi = Inventory Cost for supplier at cycle i
TCvm =Total Cost for buyer m
TCs = Total Cost for supplier s
JTC = Joint Total Cost

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