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Superiority of Collaborative Replenishment with Supply-hub in Assembly System

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Abstract: Supply replenishment mode between suppliers and the manufacturer is considered in upstream assembly system. Furthermore, collaborative replenishment mode in assembly system is analyzed based on supply-hub. To illustrate superiority of the supply-hub, the other two replenishment modes, called traditional lot-for-lot mode and modified lot-for-lot mode with "milk run", are introduced. The optimal decision-making is analyzed in these three different replenishment modes. Finally, numerical simulations are conducted and the total cost is compared with these three replenishment mode, which indicates the significance and superiority of replenishment mode with supply-hub in assembly system.

Key words: Collaborative replenishment, supply-hub, assembly system, lot-for-lot, milk-run

INTRODUCTION

In the traditional assembly system, the manufacturer determines the optimal order quantity by balancing the order cost, inventory cost and so on before sending out orders to several suppliers. Not until the receipt of orders do the suppliers begin to produce and distribute according to the order, trying hard to complete delivering materials or components ordered in a timely and effective manner. However, the above procedure may cause some problems in such industries as the automobile industry and electronic industry etc., where the final products produced by the manufacturer are usually assembled from different components provided by different suppliers. Since assembly system composes of multiple suppliers and one manufacturer, there is no doubt that different suppliers' capacity cannot guarantee to match the components synchronously, which does harm to the efficiency of production and delivery across the supply chain. Furthermore, this will eventually affect the assembling of final product and reduce effectiveness of the whole supply chain. To solve the problem of components' mismatch, some manufacturers entrust the third party logistics to manage the components provided by the upstream suppliers. As a result, the manufacturers can periodically send orders to the suppliers and the third party logistics, while the third party logistics picks up the ordered components and then deliver them directly to the manufacturer. The "milk run" mode operated by the third party logistics can not only reduce the transportation cost but also guarantee the accuracy and unity of the components' arrival on time, which alleviates the collaborative arrival problem with different components. To achieve quicker response to customers, lower costs and maintain the competitiveness in the industry, the manufacturer is starting to adopt the JIT production mode. As an effective way of supporting the assembly production in supply chain, the supply mode based on supply-hub operated by third party logistics can help to realize the JIT operation, which has been gradually widely used. Under the supply mode based on supply-hub, components for assembling are usually sent to the supply-hub by third party logistics with "milk run" mode for centralized storage. According to the manufacturer's daily demand of different components, complete sets of components will be delivered from supply-hub to the work station for assembling on time (Fig. 1).

Generally, the inventory cost of components in supply-hub is undertaken by the suppliers and only when the components reach the assembly line will the manufacturer pay the suppliers (Barnes *et al*., 2000). For example, BAX Global is responsible for Apple, Dell and IBM and other IT companies with their supplies in Southeast Asia and United Parcel Service manages goods and materials procurement for Fender overseas and achieves its integration of process in distribution. Besides, Shanghai Volkswagen and Wuhan Shenlong Automobile adopt the supply-hub mode to effectively support the mixed flow job shop manufacturing with JIT delivering components to the work station directly.

In this study, we compare the different performances in assembly system with such three different replenishment modes as traditional lot-for-lot mode, the modified lot-for-lot mode with "milk run" and collaborative

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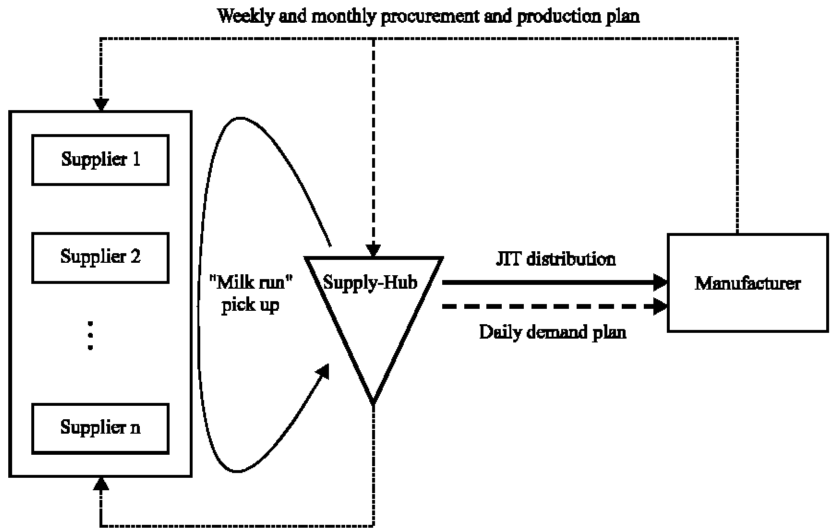

Fig. 1: Collaborative operation mode based on supply-hub

replenishment mode based on the supply-hub. The system's optimal decision-making of above three modes is also given. With the comparison in numerical simulation, the role of supply-hub is identified in improvement of performance in assembly supply chain.

LITERATURE REVIEW

Originally, traditional lot-for-lot mode has been widely used in replenishment process as it is simple and well operated. However, under this mode, there is no collaborative between the two sides. Suppliers, acting passively, cannot flexibly prepare production and delivery according to their own capacity (Cetinkaya and Lee, 2000; Disney and Towill, 2003). With the third party logistics involved in, the lot-for-lot mode with 'milk-run' picking up takes the place of traditional lot-for-lot mode and can achieve unified management of components delivery, but there still exists information distortion between the supplier and buyer. Soon Vendor Managed Inventory (VMI) has been taken as an effective way to reduce both information distortion and inventory level in supply chain (Disney and Towill, 2003; Rungtusanatham *et al*., 2007). However, the implement of VMI is more popular to the downstream retailers (manufacturer) rather than the upper suppliers. This is because that strong retailers are always using VMI as a means simply to transfer most of inventory holding costs on to those puny suppliers (Lee and Chu, 2005; Dong and Xu, 2002). However, the coming question is that whether or not it is profitable for supplier to take charge of all the inventory in supply chain. Obviously, it is not beneficial for supplier himself. With a similar spirit as ours, pioneer researchers have also proved that supplier controlling too much inventory will also l bring down the overall supply chain performance in some cases (Ru and Wang, 2010). To make it further, this paper has demonstrated it is even harmful to the manufacturer himself when adopting a too long vendor inventory liability period in VMI policy. Besides, another difference in our research is that we focus on the problem for inventory with advanced delivery, while most works are discussed the ownership of excess inventory that beyond demand.

As to supply-hub, Barnes *et al*. (2000) found that supply-hub was an innovation strategy to reduce cost and improve responsiveness used by some industries, especially in the electronics industry and it was a reflection of delaying procurement. Then they defined the concept of supply-hub first, reviewed the development of supply-hub and proposed a prerequisite of establishing supply-hub and the main way of operating supply-hub by analyzing the case of supply-hub in practice (Barnes *et al*., 2000). LI and Wang (2010) explored the operation strategy of supply-hub to achieve the joint operation management between customers and their upstream suppliers. Moreover they analyzed how to manage the supply better in vendor-managed inventory model. Furthermore, they found that the relationships between the operation strategies and performance evaluations of supply-hub were complex and nonlinear. As a result, they proposed a hierarchical structure to help the supply-hub realize the balance between different members in supply chain.

Based on supply-hub, Shihua and Fengmei (2009) developed, respectively collaborative decision-making models of production and distribution when considering the matching of distribution quantity between suppliers or not. The result illustrated after considering the matching of distribution quantity between suppliers, the total supply chain cost and the production cost of suppliers decreased significantly, but the logistics cost of manufacturers and cost of supply-hub operators increased (Shihua and Fengmei, 2009). In order to explore the effect to the supply chain design caused by the structural changes in the assembly system, LI *et al.* (2009) established a supply chain design model without supply center, single-stage supply center and two-stage supply center according to the characteristics of Bill of Material (BOM) and the relationships of multi-properties with suppliers (LI *et al.*, 2009). With the consideration that multiple suppliers provide different components to a manufacturer based on supply-hub, Hua-Ming and Shi-Hua (2010) established a economical order quantity model in such two ways as picking up separately from different suppliers and milk-run picking up. The result shows that the sensitivity to carriage quantity of the transportation cost per unit weight of components and the demand variance in different components have an influence on the choices of two picking up ways (Hua-Ming and Shi-Hua, 2010). Shihua *et al.* (2011) proposed a horizontally coordinated dual-Sourcing policy to coordinate the supply-hub model. They indicated that the total cost of supply chain can be decreased obviously while the service level is not reduced by using this horizontally coordinated replenishment policy (Shihua *et al.*, 2011). LI *et al.* (2011) gave thorough review about collaborative operation and optimization in supply logistics based on supply-hub and pointed out how to coordinate suppliers and share risks is still need to be explored (LI *et al.*, 2011).

As to the study of supply-hub, how the supply-hub played with the consolidation function was rarely discussed in detail, e.g., how to reduce the total cost of assembly system and improve the efficiency of the whole supply chain. Therefore, supply-hub is needed to perform its core competencies and coordinate the operation between each supplier and manufacturer.

This study aims to establish three cost models under three different supply replenishment modes and make full considerations of each optimal decision-making. The comparisons in numerical simulation will be carried out to show the superiority of supply-hub, which can effectively improve the performance of assembly system and enhance the competitiveness of the whole supply chain.

FORMULATION OF THE THREE REPLENISHMENT MODELS

Analysis of three replenishment modes: Three basic supply modes can be illustrated from aspects of the manufacturer's replenishment decisions-making and logistics cost as follows:

- **Traditional lot-for-lot mode:** This mode means that the manufacturer purchases components according to the planned order, while suppliers try to produce and deliver lot-for-lot sizing according to the requirements
- "Milk run" pick-up mode by third party logistics. In this mode, the manufacturer sends the purchasing information to suppliers by the planned order and controls inventory of all components. The Suppliers are permitted to produce lot-for-lot sizing continuously, but now the manufacturer, as the consignor of the third party logistics, should consider paying the third party logistics fees, of which the delivery cost is one of the most important part
- **Supply-hub mode:** Under this mode, inventory and replenishment information are managed by suppliers themselves. In Supply Hub, the inventory holding costs can be divided into two parts: one is the capital cost, shared by supplier; the other is warehouse rent and management cost, assumed by the manufacturer. Supply Hub, as the joint position of managing supply logistics of components needed by manufacturer, is necessary to master the whole materials resource plan. In order to enhance the coordination, information sharing is the effective means to improve the performance. In this way, suppliers can learn the purchase plan during the whole planned period and can produce certain components in advance. As a result, the efficiency of the production and distribution will finally be improved

Symbols and assumptions: Assume that planned unit time of the manufacturer is "week" and the weekly demand of component j is a random variable D which obeys a certain distribution. Denote component j's demand in the tth week is D_{ji}. According to the existing stock information, MRP system can process demand information and thereby get the procurement plan φ_{ijt} of the purchased components, where $0<\varphi_{ijt}<1$ and $\sum_{i=i_{beg}}^{t} \varphi_{ijt} = 1$. That means that D_{ji} in the tth week should be placed an order of proportion φ_{ijt} in the ith week.

Other parameters and variables involved in the model are as follows:

- T = Fixed planning period, which is T weeks
- S = Fixed order cost of the manufacturer
- η_1 = 0-1 variables. If the manufacturer places an order for the component j in the ith week, $\eta_1 = 1$; otherwise, $\eta_1 = 0$
- I_{ijt} = Inventory holding cost of unit component j from the ith week to the tth week
- T_j = Fixed transportation cost of component j, which is independent of quantity transported
- a_j = Unit transportation cost of component j
- P_j = Fixed production cost of component j, independent of the quantity of each batch
- c_j = Unit production cost of component j
- η_2 = 0-1 variables, under supply hub mode, if the supplier of component j arranges production in the fth week, $\eta_2 = 1$; otherwise, $\eta_2 = 0$
- φ_{fji} = Proportion of component j, planned to be delivered in the ith week, is arranged to be produced in the fth week, where $0<\varphi_{fji}<1$

According to the above definition, $D_{ji}\bullet\varphi_{ijt}\bullet\varphi_{fji}$ represents the demand of manufacturer in the tth week delivered in the ith week and arranged to be produced in the fth week.

A the proportion of capital cost in inventory cost, while aI is the capital cost and (1-a)I is the warehousing management cost.

Traditional lot-for-lot ordering mode: In this mode, in every fixed planned period, the manufacturer calculates the purchased plan of components through running MRP. Thus according to the fixed plan the manufacturer sends replenishment order every week and suppliers adopt lot-for-lot mode to arrange the production and delivery.

After calculating the procurement plan of the purchased component j by the manufacturer's running MRP in rth time and we can formulate a linear programming model as follows:

$$MLSP_1(r,j): \text{Min} \sum_{i=i_{beg}}^{i_{beg}+T-1} S\eta_1 + \sum_{i=i_{beg}}^{i_{beg}+T-1}\sum_{t=i}^{i_{beg}+T-1} I_{ijt}D_{jt}\varphi_{ijt}$$

$$\text{s.t}: \sum_{i=i_{beg}}^{t}\varphi_{ijt}=1 \quad \varphi_{ijt}\le\eta_1 \quad \varphi_{ijt}\ge 0 \quad \varphi_{ijt}\in\{0,1\}$$

In the objective function model, the first part represents the fixed order cost of sending out purchase order by the manufacture in the planned period. The second part stands for the inventory holding cost of component j between the arrival point and the time point when components are delivered to the assembly production line.

Suppose that φ^*_{ijt} and η^*_1 are optimal solution of the linear programming model $MLSP_1(r, j)$ (Cetinkaya and Lee, 2000). Thus, for the manufacturer, the purchasing cost of component j in the fixed planned period of l weeks can be expressed as:

$$C_{M1}(r,j)=\sum_{i=i_{beg}}^{i_{beg}+T-1} S\eta_1^* + \sum_{i=i_{beg}}^{i_{beg}+T-1}\sum_{t=i}^{i_{beg}+T-1} I_{ijt}D_{jt}\varphi_{ijt}^* \tag{1}$$

Given N kinds of components, calculate $C_{M1}(r, j)$ by MRP for R times and the total cost of the manufacturer can be rewritten as:

$$TC_{M1}=\sum_{j=1}^{N}\sum_{r=1}^{R} C_{M1}(r,j) \tag{2}$$

In the lot-for-lot mode, suppliers are required to meet the manufacturer's demand according to the manufacturer's replenishment decision. And the supplier's production cost of component j in the fixed planned period of l weeks can be expressed as:

$$C_{V1}(r,j)=(T_j+P_j)\sum_{i=i_{beg}}^{i_{beg}+T-1}\eta_1^* + (a_j+c_j)\sum_{i=i_{beg}}^{i_{beg}+T-1}\sum_{t=i}^{i_{beg}+T-1} D_{jt}\varphi_{ijt}^* \tag{3}$$

In formula 3, the first part represents the fixed costs of delivery and production for the supplier; the second part indicates the variable costs of delivery and production. As the inventory cost is taken by the manufacturer upon components arrival, there is no need to consider the inventory cost for suppliers.

The total costs of N suppliers after the manufacturer's running MRP for R times can be shown as:

$$TC_{V1}=\sum_{j=1}^{N}\sum_{r=1}^{R} C_{V1}(r,j) \tag{4}$$

Then the total cost of assembly system can be obtained as:

$$TC_1 = TC_{M1}+TC_{V1} \tag{5}$$

Lot-for-lot mode with milk-run picking up: When the manufacturer appoints the third party logistics to pick up components in this mode, the cost of delivery will be transferred to the manufacturer. As components are picked up, several suppliers can adopt joint transportation and fixed distribution cost will be certainly smaller than the sum of the fixed delivery cost under traditional lot-for-lot mode. However, it's not easy to quantify the decrease of transportation cost. Under conservative calculation, we still take the sum of the fixed delivery cost for each supplier's batch of the components as the fixed distribution cost under "milk run" picking up mode.

After the procurement plan of components is calculated by the manufacturer's running MRP in rth times and a linear programming model $MLSP_2(r)$ can be formulated as follows:

$$MLSP_2(r):\text{Min}\sum_{j=1}^{N}\sum_{i=i_{beg}}^{i_{beg}+T-1}(S+T_j)\eta_l+\sum_{j=1}^{N}\sum_{i=i_{beg}}^{i_{beg}+T-1}\sum_{t=i}^{i_{beg}+T-1}(a_j+I_{ijt})D_{jt}\varphi_{ijt}$$

$$\text{s.t}:\sum_{i=i_{beg}}^{t}\varphi_{ijt}=1\quad \varphi_{ijt}\le\eta_l\quad \varphi_{ijt}\ge 0\quad \varphi_{ijt}\in\{0,1\}$$

In the objective function, the first part represents the fixed order cost of purchase and delivery for the manufacturer; The second part stands for the inventory holding cost and variable delivery cost.

Suppose that φ_{ijt}** and η_l** are optimal solutions of the linear programming model $MLSP_2$ (r) (Cetinkaya and Lee, 2000). Thus, for the manufacturer, the purchasing cost of component j in the fixed planned period of l weeks can be represented as:

$$C_{M2}(r)=\sum_{j=1}^{N}\sum_{i=i_{beg}}^{i_{beg}+T-1}(S+T_j)\eta_l^{**}+\sum_{j=1}^{N}\sum_{i=i_{beg}}^{i_{beg}+T-1}\sum_{t=i}^{i_{beg}+T-1}(a_j+I_{ijt})D_{jt}\varphi_{ijt}^{**}\tag{6}$$

By running MRP for R times, the total cost of the manufacturer can be obtained:

$$TC_{M2}=\sum_{r=1}^{R}C_{M2}(r)\tag{7}$$

Suppliers still adopt the lot-for-lot mode for replenishment and the total cost of the supplier, who provides component j in the fixed planned period of l weeks, can be expressed as:

$$C_{V2}(r,j)=P_j\sum_{i=i_{beg}}^{i_{beg}+T-1}\eta_l^{**}+c_j\sum_{i=i_{beg}}^{i_{beg}+T-1}\sum_{t=i}^{i_{beg}+T-1}D_{jt}\varphi_{ijt}^{**}\tag{8}$$

After running MRP for R times, the total cost of N suppliers can be got as:

$$TC_{V2}=\sum_{j=1}^{N}\sum_{r=1}^{R}C_{V2}(r,j)\tag{9}$$

Then the entire cost of this assembly system can be formulated as:

$$TC_2 = TC_{M2}+TC_{V2}\tag{10}$$

Collaborative replenishment mode based on supply-hub: Under supply-hub mode, suppliers can share manufacturers' order plan and demand information. At the same time, suppliers take charge of components inventory in supply-hub and cannot be settled account with the manufacturer until components are delivered to the assembly line. supply-hub picks up components from each supplier with "milk run" mode and the suppliers decide independently whether to replenish, the replenishment quantity and weekly production quantity.

After running MRP for r times by the manufacturer, the supplier, who provides component j, makes the optimal decision according to the procurement plan and a linear programming model VSP(r, j) can be formulated as:

$$VSP(r,j):\text{Min}\sum_{i=i_{beg}}^{i_{beg}+T-1}P_j\eta_2+\sum_{f=i_{beg}}^{i_{beg}+T-1}\sum_{i=f}^{i_{beg}+T-1}\sum_{t=i}^{i_{beg}+T-1}(c_j+I_{ijt})D_{jt}\varphi_{ijt}\varphi_{fji}+\sum_{i=i_{beg}}^{i_{beg}+T-1}\sum_{t=i}^{i_{beg}+T-1}aI_{fji}D_{jt}\varphi_{ijt}$$

$$\text{s.t}:\sum_{i=i_{beg}}^{t}\varphi_{ijt}=1\quad \varphi_{ijt}\ge 0\quad \varphi_{fjt}\ge 0\quad \varphi_{fjt}\le\eta_2\quad \eta_2\in\{0,1\}$$

In the objective function, the first part represents the fixed production cost of component j for the supplier; the second part indicates the component j's variable production cost and the inventory holding cost from the fth week to the ith week, for they are arranged to be produced in the fth week and be delivered in the ith week. Under supply-hub mode, the ownership of the components in supply-hub belongs to suppliers. Therefore, the capital cost of components stocked in supply-hub should be taken by suppliers, which is represented by the third part in the model. And the manufacturer will take the management cost of inventory in supply-hub.

Suppose that φ_{ijt}***, η_2* and φ_{fjt}* are the optimal solutions of this linear programming VSP(r, j). Thus supplier's cost for component j in the fixed l weeks can be expressed as:

$$C_{V3}(r,j)=\sum_{f=i_{beg}}^{i_{beg}+T-1}P_j\eta_2^{*}+\sum_{f=i_{beg}}^{i_{beg}+T-1}\sum_{i=f}^{i_{beg}+T-1}\sum_{t=i}^{i_{beg}+T-1}(c_j+I_{fji})D_{jt}\varphi_{ijt}^{***}\varphi_{fji}^{*}+\sum_{i=i_{beg}}^{i_{beg}+T-1}\sum_{t=i}^{i_{beg}+T-1}aI_{ijt}D_{jt}\varphi_{ijt}^{***}\tag{11}$$

After running MRP by the manufacturer for R times, the total costs of N suppliers can be formulated as::

$$TC_{V3}=\sum_{j=1}^{N}\sum_{r=1}^{R}C_{V3}(r,j)\tag{12}$$

The manufacturer's cost in the fixed planned period of l weeks can be formulated as:

$$C_{M3}(r) = \sum_{j=1}^{N} \sum_{i=i_{beg}}^{i_{beg}+T-1} T_j \hat{\eta}_1 + \sum_{j=1}^{N} \sum_{i=i_{beg}}^{i_{beg}+T-1} \sum_{t=i}^{i_{beg}+T-1} [a_j + (1-a)I_{ijt}]D_{jt}\varphi_{ijt}^{***} \quad (13)$$

Where:

$$\hat{\eta}_1 = \begin{cases} 1 & \varphi_{ijt} > 0 \\ 0 & \varphi_{ijt} = 0 \end{cases}$$

and the first part represents the fixed costs of components delivery. The second part indicates the variable costs of delivery and the management cost in the inventory holding cost when components are stocked in supply-hub.

By running MRP for R times, we can get the total cost of the manufacturer as:

$$TC_{M3} = \sum_{r=1}^{R} C_{M3}(r) \quad (14)$$

And the entire cost of this assembly system can be obtained as:

$$TC_3 = TC_{M3} + TC_{V3} \quad (15)$$

NUMERICAL ANALYSIS AND SIMULATION

Given that it is the comparison of the superiority of three replenishment modes, some parameters in the above can be simplified. Assume that random demand variable D_{ji} obeys normal distribution with the mean value is μ, the variance is σ^2. φ_{ijt}, here just for comparison, should be fixed when the production plan is ensured. That is $\varphi_{ijt} = 1/t$, $\eta_1 = 1$, $\varphi_2 = \frac{1}{i_{beg} + T - f}$ and other related parameters are set as follows: $R = 100$, $\mu = 27$, $\sigma^2 = 36$, $I_{ijt} = 1.5+0.5(t-i)$, $a_j = 2$, $c_j = 6$, $T_j = 25$, $P_j = 25$, $\alpha = 0.3$, $N = 5$, $S = 30$ and $i_{beg} = 1$.

Based on the constructed model, set R = 100, T = 20 and the total cost of the assembly system can be calculated through Matlab. To compare the cost of both suppliers and the manufacturer in three different replenishment modes, the results can be shown in Table 1.

The histogram can be draw intuitively as follows.

In order to illustrate the total cost of assembly system influenced by T, the value of T is changed from 1 to 20. With the change of fixed planned weeks, the total cost of assembly system in three different modes can be calculated in Table 2.

As comparisons are made with the change of fixed planned weeks T, it can be drawn from Table 2 that the

Table 1: Comparison of total costs in three different replenishment modes

Total cost	Traditional lot-for-lot mode	Lot-for-lot mode with "milk-run" picking up	Supply hub mode
Manufacturer	2768800	2136400	1520100
Suppliers	2659200	1866500	1582600
Assembly system	5428000	4002900	3102700

Table 2: Comparison of total cost in three different modes with T changes

T	Traditional lot-for-lot mode	Lot-for-lot mode with "milk-run" picking up	Supply-hub mode
T = 1	169776	169357	162818
T = 2	392031	338634	301809
T = 3	624932	512785	426792
T = 4	861896	691835	550390
T = 5	1106222	872276	679483
T = 6	1354715	1057599	810813
T = 7	1603663	1248268	947815
T = 8	1871833	1445057	1088978
T = 9	2134966	1641778	1233284
T = 10	2404405	1828177	1381277
T = 11	2675151	2038027	1531108
T = 12	2953565	2241269	1688038
T = 13	3243006	2451744	1860843
T = 14	3550232	2661128	2018268
T = 15	3838951	2886527	2185709
T = 16	4151094	3098332	2369111
T = 17	4463555	3321933	2550781
T = 18	4781849	3541037	2730628
T = 19	5094439	3780942	2916771
T = 20	5428000	4002900	3102700

total cost is highest in traditional lot-for-lot mode, then lot-for lot mode with 'milk-run' picking up comes in the second place and the total cost is the least in supply-hub mode, no matter from the aspect of total cost of the manufacturer or suppliers. From the angle of the total cost of the assembly system, the total cost decreases by 0.2% to 26% when the replenishment mode is change from traditional lot-for-lot mode to lot-for-lot mode with 'milk-run' picking up. Compared with the traditional lot-for-lot mode, the total cost can drop by 4.1 to 43% when supply-hub mode is used. From the above analysis, supply-hub mode is effective with consideration of the total cost.

Second, the total cost of the assembly system also is considered with the change of demand as shown in Table 3.

It can be seen clearly from Table 3 that as demand increases the total cost also rises in three modes. The total cost under lot-for-lot mode with 'milk-run' picking up is less than under traditional lot-for-lot mode and the total cost under supply-hub mode is less than under lot-for-lot mode with 'milk-run' picking up. Taking the total cost of assembly system into account, the total cost under lot-for-lot mode with 'milk-run' picking up drops by 0.5 to 27%, compared with the traditional cycled ordering mode. The total cost can decrease by 35 to 43% when supply hub mode is used, compared with lot-for-lot mode with 'milk-run' picking up. Under supply-hub mode, the total

Table 3: Comparisons of the total cost under the three modes with changes of demand

D	Traditional lot-for-lot mode	Lot-for-lot mode with 'milk-run' picking up	Supply-hub mode
10000	919387	914831	598114
20000	1343104	1036745	699449
30000	1502576	1163753	790642
40000	1666499	1278990	881041
50000	1825272	1396474	974247
60000	1995727	1504709	1080339
70000	2155171	1618886	1175660
80000	2328716	1738933	1276972
90000	2501631	1870183	1365570
100000	2657656	1982324	1464567
110000	2825181	2100138	1563933
120000	2989753	2225558	1651728
130000	3157361	2341136	1759808
140000	3331721	2465171	1850583
150000	3493336	2575904	1946589
160000	3653474	2705363	2047257
170000	3817848	2824079	2144927
180000	3989300	2931989	2240531
190000	4148360	3064876	2335478
200000	4319662	3168859	2427823
210000	4491202	3293306	2533362
220000	4650208	3409692	2631390
230000	4824357	3544426	2723163
240000	4994950	3648400	2814366
250000	5149360	3771002	2909296
260000	5316540	3887733	3008607
270000	5487532	4014085	3104841
280000	5655335	4127737	3207639
290000	5810341	4248096	3296269
300000	5971522	4362437	3398451
310000	6152593	4488374	3494799
320000	6315489	4603424	3589343
330000	6489431	4722380	3688782
340000	6638647	4841869	3780270
350000	6807761	4961065	3883263
360000	6975352	5072635	3970962
370000	7140991	5188903	4066111
380000	7291749	5313305	4171166
390000	7475141	5438168	4269298
400000	7637987	5550278	4363090

cost of assembly system is far more less than those of the other two modes. From these aspects, supply-hub mode is preferred definitely in reducing cost.

CONCLUSION

In this study, three replenishment modes and the corresponding total cost are analyzed. In the assembly and manufacturing industries, traditional lot-for-lot mode formulates requirement plan of purchased components by MRP and sends the procurement plan to suppliers by lot-for-lot way. Under this mode, there is no collaborative between the two sides. Suppliers, acting passively, cannot flexibly prepare production and delivery according to their own capacity. Thus, traditional lot-for-lot mode leads to highest cost among the assembly system. With the third party logistics involved in, the lot-for-lot mode with 'milk-run' picking up takes the place of traditional lot-for-lot mode and can achieve unified management of components delivery, which completely save the cost caused by the suppliers' insufficient delivery capacity. Under the collaborative replenishment mode based on supply-hub, the manufacturer shares the demand plan of the purchased components with suppliers. Therefore suppliers are able to reasonably prepare production and delivery in different period according to their own capacity of production and inventory. What's more, supply-hub can complete the replenishment delivery of components in a unified way.

Upon the above analysis, three mathematical programming models under the three different modes are formulated. Through numerical analysis and simulation, the result proves that supply-hub mode, as one of the most effective replenishment modes, has a significant value in reducing the total cost (transportation and inventory cost) of assembly system.

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