Base Inventory Cooperation Strategy of Multi-parts with Supply-Hub

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Abstract

We investigate two stage supply chain optimization coordination with Supply-Hub operation mode for assembly manufacturing enterprise. Because all parts delivery of all suppliers are integrated at Supply-Hub, all needed parts by the production line are selected, packaged and then sent to the manufacturer by Supply-Hub. We applied queuing theory and basic inventory strategy to model this system and derive the optimization solution for decentralized decision and centralized decision separately. Then coordination inventory strategy is obtained by comparing decentralized decision and centralized decision. Due to inventory risk shifting from manufacturers to suppliers with Supply-Hub operation mode, backorder and holding cost subsidy contracts are used for coordination that incites suppliers to set basic inventories in favor of whole supply chain operation cost reduction. And numerical examples of three suppliers and one manufacturer are given to illustrate the effectiveness of the coordination strategy and the condition to gaining Pareto improving for whole system with the collaborative strategy.

Keywords: supply chain cooperation, base inventory, multi parts

1. Introduction

Assembly manufacturing enterprises assemble variety of parts to be finished product. These part’s suppliers have different capacity, location, etc. And thus they delivery capabilities are difficult too. It is very difficult to obtaining all needed parts whose quantity ratio met with assembly Process. The assembly manufacturer production and inventory management will be effect adversely. If there is no coordination between parts suppliers, production halts and some materials accumulation due to out of some parts’ stock will become serious phenomenon.

Therefore, it is important to coordinate inventory of parts suppliers for assembly manufacturing enterprise’s precedent supply chain management. In order to improve the coordination capacity of various suppliers supply and inventory utility, not only inventory optimization based on economic quantitative methods but also improving the supply chain network structure and operation mode can be used (Li, J. Z., et al., 2011; Ma, S. H., et al., 2009; Peral, T. P., et al., 2011; Buzacott, J. A., et al., 1992).

And in recent years, in order to improve the efficiency and effectiveness of the supply chain further, supply-hub appeared whose function is logistics integrating of upstream supply for manufacturer. Supply-hub integrates different suppliers’ inventory operation for manufacturer to realize just-in-time delivery according to real time production (Shah J., 2006; Togar, M., 2008; Guruprasad, P., 2009). Many academic articles indicated Supply-Hub can produce scale benefit and optimize assembling manufacture enterprise’s inventory and cooperate logistics operation (Yu, J. H., 2010; Li, J. Z., et al., 2011; Ma, S. H., et al., 2009). Influence for supply chain’s optimization after upstream structure changed is explored in literatures (Ma, S. H., et al., 2009; Peral, T. P., et al., 2011; Buzacott, J. A., et al., 1992).

As a coordination organization between parts suppliers and assembly manufacturers, Supply-Hub function concentration and packaging. According to the demand of manufacturers’ assembly plan, operators in Supply-Hub select needed parts and package them then delivery to the production line on time. So through the Supply-Hub, integrating suppliers, collaborating Supply logistics operation and parts synchronous supply can be realized. Manufacturers released purchase plan based on rolling time and then suppliers will launch delivery to supply-hub. Supply-Hub operators accept different parts and centralized control arrived parts inventory
Peral et al. study coordination in a two-stage capacitated supply chain with multiple suppliers (Terekhov, D., et al., 2012). They modeled the manufacturer as a queuing system and suppliers as n different M/M/1 make-to-stock queues. But they didn’t consider supply-hub mode. So, we should coordination of the decentralized supply chain with supply-hub and subsidy contract.

Most manufacturing enterprises can’t delivery product orders on time because serious backlog of raw materials supply. They have to increased raw material preparation and improve inventory levels. But the cost of finished products will increase too. So how to ensure materials on-line timely without increasing inventory levels are managers headache.

Much attention to inventory control is paid by researchers. A lot of inventory research is resulted such as lead time, the amount of raw material costs and shortages.

An important factor is the delivery of all raw materials or items that will be assembled to finished products to the manufacturing enterprises on time. Timmer et al. studied coordination way for enterprises that repeatedly review their inventories and confront Poisson demand. They analyzed steady cost allocations of the joint costs. If any group of companies has lower costs than the single companies, then allocations exist and an incentive will be given for the enterprises to coordination. They adopted two enterprises to indicate that the latter strategy has the lowest joint costs. With second strategy, the game theoretical Shapley value and the distribution rule a cost allocation in which the enterprises share the procurement cost and each pays its own holding cost are shown to be stable cost allocations. These results also hold for situations with three enterprises (Timmer, J., Chessa, M., & Boucherie, R. J., 2013).

So there are two coordination strategies can be used. First, the enterprises give their orders together for replenishment if the inventory position jointly equal to a value set in advance. Second, the enterprises reorder when one inventory level of them reaches its reorder point.

Explicitly modeling dispatch decisions with availability constraints of parts, that is important for deal with realistic supply chain problems. A dispatch problem with part availability constraints in a supply chain was considered in (Terekhov, D., et al., 2012). With two production facilities and a incorporate transit facility. Terekhov, D., et al., suggested three mixed-integer programming models and a constraint programming models and the models are compared in an extensive numerical study. If there are no parts shared among the two manufacturers, the mixed-integer programming model based on time-index variables is the best for proving best for problems with short production times while the constraint programming model tends to perform better than the others for problems with a large range of processing times.

Assemble-to-order system subject to multi parts coordination. An assemble-to-order (or ATO) system includes several parts and several products. The time to acquire or produce a part is substantial. A product is assembled only in response to demand. An ATO system combines the elements of assembly and distribution, and resolves both coordination and allocation issues. This makes the ATO systems difficult to analyze, design, and manage. The chapter also discusses one-period models, multi-period models, discrete-time models, and continuous-time models (Song, J. S., & Zipkin, P., 2003). ElHafsi, M researched a pure assemble-to-order system faced with multiple classes’ demand and compound Poisson process customer orders. Different parts were to assemble the finished product that is produced in a make-to-stock fashion. The optimal production policy of each part is a base stock dependent with state strategy. And the optimal inventory allocation policy is a multi-level state-dependent rationing policy. They find the optimal average cost rate is more sensitive to order size variability than to order size (ElHafsi, M., 2009). Zhang, X., J. Ou, & S. M. Gilbert also researched an assemble-to-order system too. They examined an assemble-to-order environment involving a short-life-cycle product that is sold in two different configurations, each requiring a unique part that must be stocked in advance. Both configurations of the product are assembled on the same equipment which has limited capacity (Zhang, X., Ou, J., & Gilbert, S. M., 2008). Reiman, M.I. and Q. Wang introduced a multi-stage stochastic program that provides a lower bound on the long-run average inventory cost of a general class of assemble-to-order inventory systems. The stochastic program also motivates a replenishment policy for these systems. They provided a set of sufficient conditions under which replenishment policy, coupled with an allocation policy, attains the lower bound (Reiman, M. I., & Wang, Q., 2012). Xiao, Y., J. Chen, and Lee, C. Y. studied a single-product, single-period assemble-to-order (ATO) model with uncertain assembly capacity. To reduce the risk/cost, the manufacturer may need to assemble in advance. They presented a profit-maximization model that makes optimal inventory and production decisions. They established structural properties of the optimal solutions, and identify the sufficient and necessary condition under which assemble-in-advance strategy should be adopted.

(Timmer, J., Chessa, M., & Boucherie, R. J., 2013).
2. Supply-Hub Operation Mode

As a coordination organization between parts suppliers and assembly manufacturers, Supply-Hub function concentration and packaging. According to the demand of manufacturers’ assembly plan, operators in Supply-Hub select needed parts and package them then delivery to the production line on time. So through the Supply-Hub, integrating suppliers, collaborating Supply logistics operation and parts synchronous supply can be realized. Manufacturers released purchase plan based on rolling time and then suppliers will launch delivery to supply-hub. Supply-Hub operators accept different parts and centralized control arrived parts inventory. The operation process of Supply-hub is shown as figure 1.

![Supply-Hub operation mode diagram](image)

**Figure 1. Supply-Hub operation mode diagram**

3. Base Stock Policy of Supply-Hub

Two stages Supply chain is considered as a closed loop network, as shown in Figure 2. One Supply-Hub and one manufacturer are in this system. The system operates as follows. Manufacturer makes to order and obtain parts from Supply-Hub but not from suppliers. And n kinds of parts stock are possessed by Supply-Hub and base stock policy is applied to manage inventories in supply-hub. Let $s_i$ be the base stock level of part $i$ for $i = 1, 2, \ldots, n$.

![Two phase closed-loop queuing system for supply chain modeling](image)

**Figure 2. Two phase closed-loop queuing system for supply chain modeling**
In the system taken into consideration, the end-customer demands arrive in single units according to a Poisson process with rate \( \lambda \), where \( \lambda \) equals to 1. And the operation in Supply-Hub is shown as Figure 3. The service times of \( n \) servers are independent and identically distributed (i.i.d.) random variables having an exponential distribution with rate \( \mu_i \) for \( i = 1, 2 \ldots n \). The manufacturer has also i.i.d. and exponentially distributed service times with rate \( \mu_M \). Let \( \rho_i \) and \( \rho_M \) be the service intensity of part \( i \) and the manufacturer, respectively, where service intensity can be defined as the ratio of the arrival rate to the service rate. For the stability of the system, it is assumed that \( 0 < \rho_i < 1 \) for \( i = 1, 2 \ldots n \) and \( 0 < \rho_M < 1 \).

![Figure 3. N kinds parts delivery to the Supply-Hub](image)

4. The Centralized and Decentralized Models

4.1 Centralized Model

\( n \) parts’ base stock level in Supply-hub is decision variables. Let \( b_i \) be the backorder cost per unit backordered for part \( i \) at Supply-hub per unit time; \( B_m \) be the backorder cost per unit backordered at the manufacturer per unit time; \( h_i \) be the holding cost per unit inventory per unit time for part \( i \) at Supply-hub. And \( h_M \) be the holding cost per unit released work-in-process (WIP) inventory per unit time for the manufacturer. In addition to the notation given above, let \( C_{si} \) denote the average cost per unit time for supplier \( i \) where \( i = 1, 2 \ldots n \), and \( C_M \) denote the average cost per unit time for the manufacturer. Then, \( C_{si} \) and \( C_M \) can be expressed as followings

\[
C_{Si}(S_1, \ldots, S_n) = b_i E[B_i] + h_i E[I_i] + h_i (\max_{i=1,\ldots,n} E[B_i] - E[B_i])
\]

\[
= (b_i - h_i)(\frac{\rho_i^{S_i+1}}{1 - \rho_i}) + h_i(S_i - \frac{\rho_i^{S_i+1}(1 - \rho_i)}{1 - \rho_i}) + h_i\max_{i=1,\ldots,n}(\frac{\rho_i^{S_i+1}}{1 - \rho_i}), \quad i = 1, \ldots n
\]

\[
C_M = (b_M + h_M)E[B_M] - \sum_{i=1}^n b_i E[B_i] - h_M\max_{i=1,\ldots,n}E[B_i]
\]

\[
C_{M}(S_1, \ldots, S_n) = (b_M + h_M)(\frac{2\rho_M^2}{1 + \rho_M})\left(\frac{1 + \rho_j(1 + \rho_M^2) - 2\rho_j^{S_j+1}(1 - \rho_j)}{2(1 + \rho_j)(1 - \rho_M)}\right) + \ldots
\]

\[
+ b_M\max_{i=1,\ldots,n}(\frac{\rho_i^{S_i+1}}{1 - \rho_i}) - \sum_{i=1}^n b_i(\frac{\rho_i^{S_i+1}}{1 - \rho_i})
\]

Where \( j = \arg\min_{i=1,\ldots,n} S_i \).

Finally, let \( C_T \) be the average total backorder and holding costs per unit time for the overall system. The
objective is to minimize $C_T$.

$$C_T(S_1,\ldots,S_n) = C_M(S_1,\ldots,S_n) + \sum_{i=1}^{n} C_{S_i}(S_1,\ldots,S_n) \quad (4)$$

According to [13][14], the unique global optimal solution to the centralized model presented in Eq. (5) is given by

$$S_i^* = \frac{\ln \left( \frac{z^*(1 - \rho_i)}{\rho_i} \right)}{\ln \rho_i}, \quad (i = 1,\ldots,n) \quad (5)$$

Where

$$z^* = \frac{\sum_{i=1}^{n} h_i}{(b_M + \sum_{i=1}^{n} h_i) \left( \frac{2 \rho_M^2}{(1 + \rho_M^2)(1 - \rho_M)} \right) - b_M - \sum_{i=1}^{n} h_i}$$

$$j = j^*, j^* = \arg \min_{j \in J} C_T(S_1,\ldots,S_n), \quad S_j = \arg \min_{i=1,\ldots,n} S_i, \quad j = 1,\ldots,n. \quad j^* = \arg \min_{i=1,\ldots,n} \rho_i$$

4.2 Decentralized Model

In decentralized decision-making model, every member of supply chain is to minimize his unit time costs. In most of practice, the basic stock level is decided by corresponding parts supplier. So the decision maker is suppliers.

$$Min \quad CH_{S_i} = (b_i - h_{M_i})E[B_i] + h_iE[I_i] + h_{M_i}, \quad \max_{k=1,\ldots,n} \left( \frac{\rho_k^{S_k+1}}{1 - \rho_k} \right) \quad (6)$$

When $i \neq k, k = \arg \max_{k=1,\ldots,n} \left( \frac{\rho_k^{S_k+1}}{1 - \rho_k} \right)$, the unique global optimal solution is Eq. (7).

$$\tilde{S}_{i}^* = \ln \left( \frac{-h_i(1 - \rho_i)}{(b_i + h_i - h_{M_i})/(\ln \rho_i)\rho_i} \right) \ln \rho_i \quad (7)$$

When $i = k, k = \arg \max_{k=1,\ldots,n} \left( \frac{\rho_k^{S_k+1}}{1 - \rho_k} \right)$, then $h_{M_i} (\max_{k=1,\ldots,n} E[B_k] - E[B_i]) = 0$

$$S_i^* = \ln \left( \frac{-h_i(1 - \rho_i)}{(b_i + h_i)/(\ln \rho_i)\rho_i} \right), \quad i \in \{1,\ldots,n\}$$

Because $0 < \rho_i < 1$, $\ln \rho_i < 0$, $S_i^* > \tilde{S}_{i}^*$, so

$$k^* = \arg \max_{k=1,\ldots,n} \left( \frac{\tilde{S}_{k}^*+1}{1 - \rho_k^*} \right)$$

$$S_i^* = \begin{cases} \ln \left( \frac{-h_i(1 - \rho_i)}{(b_i + h_i - h_{M_i})/(\ln \rho_i)\rho_i} \right) & i \neq k^* \\ \ln \left( \frac{-h_i(1 - \rho_i)}{(b_i + h_i)/(\ln \rho_i)\rho_i} \right) & i = k^* \end{cases} \quad (8)$$
4.3 Supply Chain Coordination

Comparing the centralized solution given in Eq. (5) with the decentralized solution given in Eq. (8). If \( S_i^* = S_i^0 \) for all parts, supply chain is coordinated. Otherwise, a coordination mechanism should be investigated between supplier \( i \) and the manufacturer. If \( S_i^* < S_i^0 \), for part \( i \), a coordinating contract has to decrease the base stock level of supplier \( i \). On the other hand, if \( S_i^* > S_i^0 \) for part \( i \), the manufacturer should design a contract to encourage supplier \( i \) to choose a higher base stock level than decentralized solution.

So for supply chain collaboration, manufacturers should compensate inventory and backorder partial cost for suppliers whose decentralized solution do not equivalent to system centralized solution. And backorder and holding cost subsidy contracts is investigated to coordinate the supply chain.

In the backorder cost subsidy contract, the manufacturer pays the supplier \( \alpha_{B_i} b_i \) per unit backordered, where \( 0 < \alpha_{B_i} < 1, i \in \{1, \ldots, n\} \). Then, after the subsidy, the average cost function per unit time for supplier \( i \) is modified to Eq. (9)

\[
C_{B_i}^H(S_i) = \begin{cases} 
(1 - \alpha_{B_i})b_i\left(1 - \frac{\rho_i^{S_i+1}}{1 - \rho_i}\right) + h_i(S_i - \frac{\rho_i(1 - \rho_i^{S_i+1})}{1 - \rho_i}) + h_i(\max_{k = 1, \ldots, n}(\frac{\rho_k^{S_k+1}}{1 - \rho_k} - \frac{\rho_k^{S_k+1} + 1}{1 - \rho_k})) & \text{if } i = k \\
(1 - \alpha_{B_i})b_i\left(1 - \frac{\rho_i^{S_i+1}}{1 - \rho_i}\right) + h_i(S_i - \frac{\rho_i(1 - \rho_i^{S_i+1})}{1 - \rho_i}) & \text{if } i \neq k 
\end{cases}
\]

Similarly, in the holding cost subsidy contract, the manufacturer pays the supplier \( \alpha_{H_i} h_i \) per unit inventory at the supplier per unit time, where \( 0 < \alpha_{H_i} < 1, i \in \{1, \ldots, n\} \). Then, after the transfer payment, the average cost function per unit time for supplier \( i \) is Eq. (10)

\[
C_{H_i}^H(S_i) = \begin{cases} 
\rho_i^{S_i+1}(1 - \frac{1}{\rho_i}) + (1 - \alpha_{H_i})\left[1 + h_i(S_i - \frac{\rho_i(1 - \rho_i^{S_i+1})}{1 - \rho_i}) + h_i(\max_{k = 1, \ldots, n}(\frac{\rho_k^{S_k+1}}{1 - \rho_k} - \frac{\rho_k^{S_k+1} + 1}{1 - \rho_k}))\right] & \text{if } i = k \\
\rho_i^{S_i+1}(1 - \frac{1}{\rho_i}) + (1 - \alpha_{H_i})h_i(S_i - \frac{\rho_i(1 - \rho_i^{S_i+1})}{1 - \rho_i}) & \text{if } i \neq k 
\end{cases}
\]

After calculation, the value of \( \alpha_{B_i} \) and \( \alpha_{H_i} \) is as

\[
\alpha_{B_i} = \begin{cases} 
\frac{1 + \frac{b_i}{h_i} z^{b_i}(\ln \rho_i)}{1 + \frac{h_i}{b_i} + z^{b_i}(\ln \rho_i)} & \text{if } S_i^0 < S_i^0, i \neq k \\
\frac{1 + \frac{b_i}{h_i} z^{b_i}(\ln \rho_i)}{1 + \frac{h_i}{b_i} + z^{b_i}(\ln \rho_i)} & \text{if } S_i^0 < S_i^0, i = k 
\end{cases}
\]

\[
\alpha_{H_i} = \begin{cases} 
\frac{1 + \frac{z^b(\ln \rho_i)}{h_i}}{1 + \frac{z^b(\ln \rho_i)}{h_i} z^b(\ln \rho_i)} & \text{if } S_i^0 < S_i^0, i \neq k \\
\frac{1 + \frac{z^b(\ln \rho_i)}{h_i}}{1 + \frac{z^b(\ln \rho_i)}{h_i} z^b(\ln \rho_i)} & \text{if } S_i^0 < S_i^0, i = k 
\end{cases}
\]

5. Numerical Example

A supply chain with three suppliers and a manufacturer is considered in numerical examples. There are 5 groups of parameters. The parameters are taken from [13] partially and given in the Table 1. Decentralized solution and centralized solution are depicted in Table 2 and Fig. 4 for suppliers 1, 2, 3. \( S_i^0 \) presents the centralized solution \( S_i^0 \) and decentralized solution. As we can see from Table 2 and Figure 4 that average total costs per unit time of centralized system is always lower than the one of decentralized system. And we find that the cost of supplier will decrease while Manufacturers will not alwaysafter backorder and holding cost subsidy contracts.

Table 3 presents result after backorder and holding cost subsidy contracts. CP(%) is defined as the competition penalty as the percentage increase of the decentralized system over the backorder and holding cost subsidy policy system according to the average total costs per unit time. So whether Pareto improvement after coordination can be find out. “YES” or “NO” in the last column mean there is Pareto improvement or not.

We find that the cost of supplier will decrease while Manufacturers will not alwaysafter backorder and holding cost subsidy contracts. When \( CP_M^\% \) is negative value, manufacturers interests is damaged and no system Pareto improvement. In this simulation examples, the third suppliers to improve effect is the best.
Table 1. The data set (input parameter)

<table>
<thead>
<tr>
<th>No.</th>
<th>Service intensity</th>
<th>( \rho_1 )</th>
<th>( \rho_2 )</th>
<th>( \rho_3 )</th>
<th>( \rho_M )</th>
<th>( h_1 )</th>
<th>( h_2 )</th>
<th>( h_3 )</th>
<th>( h_M )</th>
<th>( b_1 )</th>
<th>( b_2 )</th>
<th>( b_3 )</th>
<th>( b_M )</th>
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<td>0.82</td>
<td>0.84</td>
<td>5</td>
<td>1.01</td>
<td>3.73</td>
<td>9.74</td>
<td>96.9</td>
<td>59.72</td>
<td>92.62</td>
<td>96.9</td>
<td>302.15</td>
</tr>
<tr>
<td>2</td>
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<td>0.81</td>
<td>0.59</td>
<td>3.54</td>
<td>4.36</td>
<td>3.64</td>
<td>11.54</td>
<td>92.6</td>
<td>85.38</td>
<td>81.67</td>
<td>92.6</td>
<td>370.94</td>
</tr>
<tr>
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<td>0.86</td>
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<td>3.16</td>
<td>10.96</td>
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<tr>
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<td>0.62</td>
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<td>1.27</td>
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<td>87.56</td>
<td>91.43</td>
<td>81.5</td>
<td>403.74</td>
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Table 2. The centralized and decentralized solutions

<table>
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<tr>
<th>No.</th>
<th>( S_1^* )</th>
<th>( S_2^* )</th>
<th>( S_3^* )</th>
<th>( S_1^o )</th>
<th>( S_2^o )</th>
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<td>37.561</td>
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<td>4.706</td>
<td>27.809</td>
<td>32.862</td>
<td>5.468</td>
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</tbody>
</table>

Figure 4. System performance comparison between centralized and decentralized models solutions
Table 3. The competition penalties for the suppliers and the manufacturer under the backorder and holding cost subsidy contracts and the contract parameters

<table>
<thead>
<tr>
<th>NO</th>
<th>$\alpha_{B1}$</th>
<th>$\alpha_{B2}$</th>
<th>$\alpha_{B3}$</th>
<th>$\alpha_{H1}$</th>
<th>$\alpha_{H2}$</th>
<th>$\alpha_{H3}$</th>
<th>$CP_1$ (%)</th>
<th>$CP_2$ (%)</th>
<th>$CP_3$ (%)</th>
<th>$CP_M$ (%)</th>
<th>Pareto improving</th>
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<td>0.689</td>
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<td>0</td>
<td>0</td>
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<td>0</td>
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<td>13.464</td>
<td>16.397</td>
<td>3.2643</td>
<td>Yes</td>
</tr>
</tbody>
</table>

average value: 61.3594, 37.2866, 75.2528, 1.29766

6. Conclusion

This paper investigates Supply chain coordination of the assembly manufacturer with Supply-Hub operation modes. All parts delivery of all suppliers are integrated at Supply-Hub. And needed parts on the production line are selected and packaged and sent to the manufacturer by Supply-Hub. The system is modeled as continuous queue and interarrival times of the manufacture are derived using an approximate distribution. Through the comparison, it can be seen that the average total costs per unit time of centralized system is always lower than the one of decentralized system. And the system with certain parameters can be coordinated by backorder and holding cost subsidy contracts. And these coordinated contracts are Pareto improving for whole system.

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