ORDER ALLOCATION AMONG MULTIPLE SUPPLIES BY PRODUCTION LOAD EQUILIBRIUM

Wei Xiang¹, Fashuai Song¹ and Feifan Ye²*
¹ School of Mechanical Engineering and Mechanics
Ningbo University, China
xiangwei@nbu.edu.cn, songfashuai@163.com

²School of Business
Shaoxing University, China
yefeifan@nbu.edu.cn

ABSTRACT

In the situation of multiple sourcing, a manufacturing enterprise (purchaser) purchases the same item from more than one vendor. In this paper, a new strategy for order splitting is proposed, in which an order is allocated among a group of supplies according to their production load equilibrium. The order allocation model by the proposed new strategies is developed. Considering the uncertainties of demand and production capacity of enterprises, the discrete event system simulation is used to verify the production load equilibrium strategy comparing with the normal capacity-based strategy. The results show that production load equilibrium strategy can not only guarantee the order’s lead time, but also balance the utilization of suppliers’ production resources. The proposed order allocation strategy can benefit both purchaser and supplies in a supply chain.
1 INTRODUCTION

A useful approach to ensure the reliability of a manufacturer’s supply stream in a make-to-order environment is to follow a multiple sourcing strategy. In this situation, a manufacturing enterprise (purchaser) purchases the same items from more than one vendor and the total demand is split among them. How to allocate the manufacturer’s order is one of the key problems in supply chains management.

In the researches of order allocation, the order-related indicators, like price, quality, on-time delivery (OTD), etc. are often employed as the evaluation or allocation criteria. Typical work is reported by Pan[1], Qi[2] and Yang et al[3]. However, these studies usually solve problem from the purchaser’s perspective and are less beneficial to maintain the strategic cooperative partnership with suppliers. In fact, especially in the case of manufacturer and suppliers being in long-term stable cooperative relationship, the price and the quality of products by suppliers usually tends to be less important, while the production status of the supplier during the order’s lead time tends to be more important to ensure the sustainability of the supply chains. Korpela et al[4] pointed out that suppliers’ limited production capacity should be allocated reasonably for the optimization of the overall supply chain. Sanayei et al[5] applied the multi-attribute utility theory and linear programming to study the suppliers’ selection and order allocation, considering the supplier production capacity constraints. However, allocating orders among a group of suppliers by their currently available capacity is more reasonable than by their total or potential capacity. Therefore, the production load equilibrium among suppliers could be employed as a criterion in order allocation. Cheng et al[6] established a multi-objective optimization model of comprehensive cost minimization and production load equilibrium for order allocation problem. In this paper, in order to evaluate the performance of different order allocation strategies in dynamic environment for a long period, we use the discrete event simulation (DES) to study the order allocation problem by production load equilibrium among a group of suppliers within an industry cluster, in which the differences in price and quality are less important than the suppliers are in different places of the world.

2 MODEL OF ORDER ALLOCATION STRATEGY

2.1 Notations

Several parameters and variables used in the order allocation model are expressed as follows:

\( i \): Numbers of suppliers in supply chain, \( i = 1, 2, \ldots, n \);

\( j \): Numbers of manufacturers in supply chain; \( j = 1, 2, \ldots, m \): for the case of 1 manufacturer \( \rightarrow n \) suppliers model, \( m = 1 \);

\( t \): Index of periods, \( t = 1, 2, \ldots, T \);

\( C_i \): Capacity limit of supplier \( i \) of a product

\( O_{it} \): Order quantity received from other enterprise of supplier \( i \) at period \( t \)

\( D_t \): Demand of manufacturer at period \( t \)

\( P_{ti} \): Manufacturer’s order quantity to supplier \( i \) at period \( t \)

\( S_{t,i} \): Unfinished order quantity of supplier \( i \) at period \( t \), \( S_{t,i} = \max(P_{ti} + O_{t,i} + S_{t-1,i} - C_i, 0) \), in which \( S_{0,i} = 0 \);

\( r_{t,i} \): on-time delivery rate of supplier \( i \) at period \( t \).

2.2 Order allocation model under load-equilibrium

The production load rate indicates the ratio of the enterprise’s current production tasks and its maximum capacity. The production load-equilibrium allocation strategy is aimed at the production load equilibrium among all suppliers. Two basic concepts, the pre-defined
production load rate and the current production load rate, are defined firstly to describe this strategy clearly.

The pre-defined production load rate indicates the average production load each supplier should reach theoretically. It is the ratio of total order in this cycle to all suppliers' total production capacity as shown in Equation (1).

$$\frac{\sum_{t} (O_i + S_{i,t-1}) + D_t}{\sum_{t} C_i}$$ \tag{1}

Where the fractional part represents the sum of the orders in one period which includes all suppliers' order quantity received from other enterprise, unfinished order quantity at the previous period and manufacturers' orders at this period.

The current production load rate indicates a specific supplier's current production load rate at the very beginning of a cycle period before manufacturer allocate its orders. It is the ratio of the existing order quantity of a cycle to the supplier's production capacity as shown in (2).

$$\frac{O_i + S_{i,t-1}}{C_i}$$ \tag{2}

Where the fractional part represents the initial order of a cycle period, which includes order quantity received from other enterprise of suppliers i, and unfinished order quantity at last period.

The production load-equilibrium allocation strategy ensures the relative equilibrium among all suppliers. Therefore, different allocation models are adopted under different situations by comparing the pre-defined production load rate with the current production load rate as shown in (3), (4) and (5):

a) for $$\forall i$$, $$\frac{\sum_{t} (O_i + S_{i,t-1}) + D_t}{\sum_{t} C_i} \geq \frac{O_i + S_{i,t-1}}{C_i}$$, then

$$P_i = \left( \frac{\sum_{t} (O_i + S_{i,t-1}) + D_t}{\sum_{t} C_i} - \frac{O_i + S_{i,t-1}}{C_i} \right) \cdot C_i$$ \tag{3}

Equation (4) shows that when all suppliers’ current existing production load are less than or equal to the pre-defined production load in the beginning of a cycle, manufacturer allocate its orders to all suppliers with the principle of balancing each supplier’s production load.

b) for $$\exists i = k$$, $$\frac{\sum_{t} (O_i + S_{i,t-1}) + D_t}{\sum_{t} C_i} < \frac{O_i + S_{i,t-1}}{C_i}$$, then

$$P_i = \left( \frac{\sum_{t} (O_i + S_{i,t-1}) + D_t}{\sum_{t} C_i} - \frac{O_i + S_{i,t-1}}{C_i} \right) \cdot C_i$$ \tag{4}

When $$i \neq k$$, $$P_i = 0$$

When $$i = k$$, $$P_k = 0$$ \tag{5}

Equation (5) shows that in the beginning of a period, if the current existing production load of supplier k is greater than its pre-defined production load, then the manufacturer (purchaser) will no longer allocate orders to supplier k in this cycle, namely $$P_k = 0$$: Equation (4) shows that manufacturer allocate its orders to the rest suppliers with the principle of balancing the rest supplier's production load, ensuring the rest suppliers' production load
equal and less than the pre-defined production load, and also ensuring the pre-defined production load less than the current production load of supplier \( k \).

Performance measurement is a critical part of the model. Three indexes, manufacturer’s on-time delivery (OTD) \( R_{it} \), supplier’s average production load rate \( Q_{it} \), and supplier’s production load fluctuation \( S_{2i} \), are introduced to evaluate the performance of suppliers.

3 SIMULATION STUDIES

To evaluate the order allocation strategies both by production capacity and by production load equilibrium, two simulation cases are designed based on the operation data of a mechanical manufacturing enterprise (Purchaser). The purchaser’s order demand and its three suppliers’ production data within 21 months are collected and several statistics analysis results are achieved in Table 1.

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Mean value</th>
<th>Variance</th>
<th>Maximum capacity</th>
<th>The current production load rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier 1</td>
<td>73.5</td>
<td>70.2</td>
<td>210</td>
<td>35%</td>
</tr>
<tr>
<td>Supplier 2</td>
<td>108.1</td>
<td>168.3</td>
<td>159</td>
<td>68%</td>
</tr>
<tr>
<td>Supplier 3</td>
<td>62.1</td>
<td>40.9</td>
<td>138</td>
<td>45%</td>
</tr>
<tr>
<td>Manufacturer</td>
<td>101.4</td>
<td>124.3</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Case 1: The production load rates among suppliers are disequilibrium severely.

The average production load rate of all three suppliers is shown in Fig 1 and the on-time delivery is shown in Fig 2 under two order allocation strategies in the case that the production load rates among all the three suppliers are disequilibrium severely. By production capacity allocation strategy, the difference of production load rates among suppliers is much bigger. In this situation, the suppliers’ overall load rate is only 71.83%, but the highest load rate of a supplier reaches to 113.44%, which is overloaded. Meanwhile, the frequency of OTD that is lower than 94% is up to 30%, which influences the purchaser’s production seriously. However, by load equilibrium strategy, each supplier’s production load rate are 67.62%, 78.39% and 67.72% respectively. The production load of supply 2 keeps high due to its initial production load is relative high. The rest two suppliers’ production load almost keeps consistent. Moreover, the load equilibrium strategy still ensures the OTD rate at 100%.

Figure 1: The average production load rate of suppliers
Case 2: The production load of all suppliers is at high level.

The corresponding average production load rate and the manufacturer OTD by two strategies are shown in Fig 3 and Fig 4 in the situation of all suppliers production load are at high level. By production capacity allocation strategy, when the suppliers’ overall load rate reaches to 94.30%, it already makes the issued orders fail to be delivered on time frequently and one supplier is overloaded. However, by load rate equilibrium strategy for order allocation, even when the suppliers’ overall load rate reaches to 97.29%, the order fulfilment is still better than the capacity based strategy, and each supplier’s production load rate are relatively equilibrium around 97.32%.

The simulation results indicates that the load equilibrium allocation strategy increases suppliers’ overall resource utilization 3% at least than by the production capacity based allocation strategy, and therefore improves the entire supply chain operation. By comprehensive comparison of case 1 and case 2, we find that the smaller production load difference among suppliers is, the higher the overall resources utilization rate in whole supply chain is. Meanwhile, the better operation of all suppliers means better satisfaction to the needs of the manufacturing enterprise (purchaser).
The variance of the suppliers’ production load in a period is also simulated by production capacity and load equilibrium strategy respectively under the condition of case 1 and case 2 and the results are shown in table 2. By load equilibrium allocation strategy, the supplier’s production load fluctuation during the simulated time is much less than by production capacity strategies either in case 1 or in case 2. The reduced production load fluctuation in a period is conducive to improve supplier’s resources utilization, and furthermore to meet the purchaser’s needs better.

Table 2: Supplier production load fluctuation

<table>
<thead>
<tr>
<th>Case number</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier number</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Production capacity strategy</td>
<td>73.42</td>
<td>834.27</td>
</tr>
<tr>
<td>Load equilibrium strategy</td>
<td>53.42</td>
<td>234.73</td>
</tr>
</tbody>
</table>

4 CONCLUSIONS

The order allocation problem for the custom-engineered product manufacturer adopting multiple sourcing from a number of suppliers within an industry cluster is studied in this paper under the assumption of the long-term partnership between the manufacturer (purchaser) and the suppliers. It is considered that in this situation, the traditional order allocation criteria such as price and quality are less important and the capacity related criterion is more important. The manufacturer should split its order in the perspective of whole supply chains in order to keep its stable operation and sustainable development. Reducing the production load rate differences among suppliers at a time and reducing the production load rate fluctuation in a period in each supplier are not only beneficial to increase resources utilization of the suppliers, but also beneficial to satisfy the demand of the manufacturer (purchaser). By simulation study, the following results are found by comparing the two order allocation strategies of production capacity and load equilibrium.

In the situation of severe disequilibrium of suppliers’ production load rate, the production capacity based strategy makes the difference of each supplier’s production load even bigger and leads to the fail of OTD frequently. However, order allocating by load equilibrium strategy makes each supplier’s production load be balanced and ensures the 100% OTD. In the situation that all suppliers’ production loads are at high level, the load equilibrium allocation strategy maintains better OTD than the capacity based strategy, and each supplier’s production load are relatively equilibrium. In the situation that all suppliers’ production loads are at low level, it is obviously that the two allocation strategies have little difference to both the suppliers and the purchaser. That is why we do not discuss this situation in the paper.
Order allocation strategy by production load equilibrium can not only make a balanced production load rats among suppliers during the lead time of an order but also make each supplier’s production load less changeable if the purchaser keeps taking this order allocation strategy for a long time. Furthermore, the balance of production load in each enterprise in a supply chain will obviously improve the resource efficiency of the whole supply chain. However, simulation result suggests that the capacity based allocation strategy will greatly magnify the production load fluctuation in a supply chain.

5 REFERENCES


