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Selecting Suppliers with Shortage Risk and Outsourcing Cost for a Make-to-Order Manufacturer

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ABSTRACT

Make-to-Order manufacturers often encounter the following dilemma: The order comes irregularly and it would cost too much to finish the order on time because the lead time is sensitive and multiple custom parts are not stocked. By introducing a frontier method based on Data Envelopment Analysis technique, this paper helps MTO manufacturers to determine the portfolios through calculating their efficiencies while considering two main factors, shortage risk and associated cost simultaneously. The method provides a pool of frontier portfolios ranging from less shortage risk and higher cost to high shortage risk and less cost. It gives MTO manufacturers flexibility to choose the optimal solution according to the MTO manufacturers' preference.

KEYWORDS: Data envelopment analysis (DEA); Make-to-order; Supplier selection; Portfolio

INTRODUCTION

Make-to-order's mode of production has been widely applied in various economic activities and makes products from small birthday gifts to large-scale precision instruments. In contrast to a regular mode, MTO can satisfy all special needs of customers while more time and money are spent in the production preparation stage, which can be severely compromised when parts are multiple or the time is sensitive.

Any MTO manufacturer who has multiple parts and irregular orders would experience this dilemma. As the production quality and delivery time, which can be summarized as delivery performance, are highly related with sourcing suppliers, one possible solution for MTO manufacturers is to establish the long term cooperation relationship with suppliers to assure the delivery performance of orders with appropriate cost.

Treating sourcing suppliers as partners has several advantages. As the Gartner Group analyzes in a recent report, it contributes to the construction of manufacturers' capability building, the improvement of global business growth and the increase of efficiency and profitability . For instance, by developing strong co-operative relationship with sourcing suppliers, Toyota Australia has achieved great performance improvements in information sharing, cost reduction and high level of trust, etc . Moreover, lots of manufacturers have adopted the suggestion of traditional Deming's quality management theory to coordinate with single sourcing partner for better relationship maintenance.

However, in the fast changing business environment, MTO manufacturers need to cooperate with multiple suppliers to guarantee the delivery time at a reduced cost, especially when the time left for bidding is pressed. Therefore, there should be a useful tool to help the MTO manufacturer select the sourcing partners and determine the associated quantity allocation for each selected supplier.

MODEL

We consider the case that a MTO manufacturer needs multiple kinds of custom parts for an order with a due date. For each custom part, there are many certified suppliers qualified in providing the exact custom part. The production department cannot start the assembling and debugging works until it receives all the required custom parts. At the request of the due date and desirable service level, the MTO manufacturer needs to choose the suppliers and determine the portfolio, i.e., the quantity allocated to each selected suppliers for each custom part. The quantity allocated to each supplier is according to the suppliers' cost structure, process speed, product quality and available capacity. Although there are many other factors that may influence the choice of suppliers, the on time probability and the associated cost are the two most important key factors as we discussed above. In this research, we collect the information of suppliers, and calculate the on time probability and cost of different sourcing portfolios based on this information.

Assuming there are m custom parts in one particular order. For each custom part i (i = 1, 2, …, m), Ni units are needed. There are ki certified suppliers available for part i. Let nij be the assigned units of part i to supplier Sij (i = 1, 2, …, m; j = 1, 2, …, ki). To satisfy the need of custom part i , we have

$$\sum_{j=1}^{k_i} n_{ij} = N_i. \tag{1}$$

Before we determine the units of part i assigned to supplier Sij, the MTO manufacturer first needs to check the availability of the supplier. Each supplier may have numerous jobs on-hand from various sources. Without losing generality, we assume that the supplier must finish its on-hand jobs before beginning the production for the MTO manufacturer's new order. Assume the Sij supplier's processing time for each unit of custom part i is tij, whether it is good or defective.

Although the on-hand jobs may process different parts, they can be converted into the same unit according to the aggregate plan. Denote Oij as the aggregated units of custom part i of the total existing on-hand jobs of supplier Sij. Let T be the order due time. If the supplier cannot finish the existing jobs by time T, it will be unavailable for the new order. Thus, the supplier Sij cannot be considered for the new order unless it satisfies the following condition

$$O_{ij} \times t_{ij} \leq T \tag{2}$$

If condition (2) is satisfied, the quantity nij allocated to supplier Sij must satisfy the following relation.

$$n_{ij} \leq \overline{n_{ij}} = \lfloor T / t_{ij} \rfloor - O_{ij} \tag{3}$$

In equation (3), $\lfloor x \rfloor$ represents the highest integer no larger than x, and $\overline{n_{ij}}$ is the upper bound units of part i allocated to supplier Sij within time T.

In order to fulfill the order, the supplier needs to produce ($n_{ij} + O_{ij}$) good (aggregate) units of custom part i by the due time T, where Oij is from the existing on-hand jobs and nij is a decision variable for the new order. Let Rij be non-defective rate of the jth supplier Sij when it makes part i. Since defective units can be produced, the total production units (both good and defective) can be any number between ($n_{ij} + O_{ij}$) and ($\overline{n_{ij}} + O_{ij}$) by due time T, and it follows a Negative Binominal (Pascal) distribution. The probability for supplier Sij to finish and delivery the assigned units nij by due time T is

$$P_{ij}(n_{ij}) = \begin{cases} 0, \ if \ \ n_{ij} \geq \overline{n_{ij}}; \\ \displaystyle\sum_{k=n_{ij}+O_{ij}}^{\overline{n_{ij}}+O_{ij}} \binom{k-1}{n_{ij}+O_{ij}-1} (R_{ij})^{(n_{ij}+O_{ij})} (1-R_{ij})^{(k-n_{ij}-O_{ij})}, \ \ if \ \ 0 < n_{ij} \leq \overline{n_{ij}}; \\ 1, \ if \ \ n_{ij} = 0. \end{cases} \tag{4}$$

The cost of sourcing nij units of part i to supplier Sij has two components: the fixed cost and the variable cost. The fixed cost is associated with the selection of supplier j to produce part i, no matter what the quantity is. The variable cost is associated with the production units. Let Fij be the fixed cost when supplier j is selected to produce part i, Vij be the unit cost of producing part i by supplier j. The cost of sourcing nij units of part i from supplier j is:

$$C_{ij}(n_{ij}) = F_{ij} * b_{ij} + V_{ij} * n_{ij}$$
$$where \ \ b_{ij} = \begin{cases} 0, \ if \ \ n_{ij} = 0; \\ 1, \ if \ \ n_{ij} > 0. \end{cases} \tag{5}$$

In equation (5), bij is a binary variable and it is equal to one if supplier Sij is selected and zero otherwise.

In practice, if more than one suppliers are selected for a particular custom part i, a given set of quantity allocation nij (j = 1, 2, …, ki) is called a part portfolio. This part is delivered on time if and only if all suppliers finish the production and delivery by due time, and the on time probability of custom part i by a given due time T is

$$P_i(n_{ij}, j = 1,2,...,k_i) = \prod_{j=1}^{k_i} p_{ij}(n_{ij}). \tag{6}$$

The related cost function for sourcing custom part i is obtained by the sum of the cost function of all ki certified suppliers for custom part i

$$C_i(n_{ij}, j = 1,2,...,k_i) = \sum_{j=1}^{k_i} C_{ij}(n_{ij}). \tag{7}$$

Similarly, the order on time probability of all custom parts is

$$P(i = 1,2,...,m; j = 1,2,...,k_i) = \prod_{i=1}^{m} p_i(n_{ij}, j = 1,2,...,k_i). \tag{8}$$

The associated order cost of sourcing all custom parts is the addition of the sourcing cost of all custom parts

$$C(i = 1,2,...,m; j = 1,2,...,k_i) = \sum_{i=1}^{m} C_i(n_{ij}, k = 1,2,...,k_i). \tag{9}$$

Once the MTO manufacturer determines a portfolio for each custom part, the final order on time probability and order cost are obtained by the (8) and (9). An order portfolio, denoted as nij (i = 1, 2, …, m; j = 1, 2, …, ki), is a combination of quantity allocation decision for all custom parts to part suppliers. In practice, it is required that the on time probability for an order must be no less than a desirable service level (such as 95%).

Two criteria, cost and on time probability, are used to compare every two portfolios, whether they are part or order portfolios. If one portfolio has lower cost and higher on time probability than the other, this portfolio is superior to the other one. However, a superior relationship may not always exist between two portfolios. In many cases, we may see that one portfolio has lower cost but lower on time probability. In this situation, we cannot get to a the conclusion of which portfolio is superior. Instead, we can find more than one superior portfolio.

Superior portfolio has the following properties: any superior portfolio has no any other portfolio superior to it, but any non-superior (inferior) portfolio has at least one portfolio which is superior to it. However, a superior portfolio may not be in a frontier. DEA method is a perfect tool to eliminate relative inefficient superior portfolios and keeps the relative efficient ones to form the frontier portfolios. The frontier portfolios are the possible solutions to recommend to the decision makers for the custom part sourcing decision.

We suggest two steps to obtain the frontier portfolios. First, we modify two algorithms introduced by Yue, et al. to obtain the part superior portfolios, and then the order superior portfolios. Unlike the previous algorithm used by Yue et al. which only obtain a limited number of superior portfolios, the introduced new algorithms will obtain all possible superior portfolios. Second, we introduce the DEA method to obtain relative efficient superior portfolios to form the frontier portfolios. Obtaining all possible portfolios and utilizing DEA to eliminate the inefficient portfolios to form the relative efficient frontier portfolios are the major contributions of this research. The idea of the modified two superior portfolio searching algorithms is given in this section and detailed procedure is provided in the Appendix. The DEA approach of the second step is introduced in the next section.

Part superior portfolio search

The procedure begins with the part superior portfolio search for a particular custom part i (i=1, 2, …, m) with Ni items and ki certified suppliers. There are total ki ! number of part supplier combinations for part i. Unlike the research of Yue et al. [5] which only provides the maximum probability portfolio for each combination of the suppliers, we modified the search algorithms and obtained all possible superior portfolios for each supplier combination for any part.

Order superior portfolio search

After the part superior portfolios are determined for all custom parts, the decision maker can use each superior portfolio from each part and combine them to form an order superior portfolio candidate. Equations (8) and (9) are used to calculate the order on time probability and order cost for the order superior portfolio candidate. If such an order superior portfolio candidate is inferior to any other candidate or its on time probability is less than desired service level, it will not be in the order superior portfolio pool. Only the order portfolio which meets the desired service level and is not inferior to any other order portfolio is included in the order superior portfolio pool. Repeating this procedure for all possible combination (one superior part portfolio from one part), we can determine all possible order superior portfolios. However, an order superior portfolio doesn't mean it is relative efficient comparing with other portfolios. Therefore we introduce DEA model to eliminate inefficient superior portfolios and obtain the order frontier portfolios in the following section.

DEA MODEL

In this section, we use the DEA method to obtain the efficient portfolios from the order superior portfolios pool and form the frontier portfolios.

In the previous section, all order superior portfolios are obtained. Without losing generality, assume there are n number of order superior portfolios and each of them is a DMU (Decision Making Unit) in the DEA model, denoted as DMUd (d = 1, 2, …, n). Since all these DMUs aim to complete the delivery job and they have finished indeed, we assume the output of each DMU to be a constant with the value of one, and the associated cost and on time probability are the two attributes of each DMU. Notice that in the DEA technique, if outputs are the same, DMUs with less input have better performance. Thus we define the order cost of the portfolio as one input and the shortage risk as the other input which can be defined as one subtracting on time probability (shortage risk = 1 – on time probability).

For DMUd, denote its two inputs as xid (i =1, 2), where x1d and x2d are the cost and shortage risk respectively (x1d = C(i =1,2,…,m; j=1,2,…,ki), and x2d = 1- P(i =1,2,…,m; j=1,2, …,ki)), the constant output for DMUd as yd, which has the value of one. The relative efficiency for DMUd, denoted as θd , can be obtained by the following CCR model:

$$\begin{aligned} \max\ \theta_d &= \frac{y_d}{\sum v_i x_{id}} \\ \frac{y_j}{\sum v_i x_{ij}} &\le 1, j = 1,\dots,n \\ v_i &\ge 0, i = 1,2. \end{aligned} \tag{10}$$

Since above model is a fractional programming and the numerator of the fraction is the constant, we change the model (10) to the following programming:

$$\begin{aligned} \min\ \eta_d &= \sum v_i x_{id} \\ \sum v_i x_{ij} &\ge 1, j = 1,\dots,n \\ v_i &\ge 0, i = 1,2. \end{aligned} \tag{11}$$

The efficiency of DMUd can be calculated from the equation $\theta_d = 1/\eta_d$. The DMU whose efficiency score equals one is relatively efficient and viewed as the order frontier portfolios.

CONCLUSIONS

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MTO manufacturers have always faced such dilemma that it should accomplish the customers' orders in a rush time and maintain a necessary desirable service level with appropriate cost. Considering it costs too much time and money in the sourcing stage as there are multiple custom parts which are not stocked in advance, one possible solution for MTO manufacturers is to cooperate with sourcing suppliers to assure the delivery performance with acceptable cost. Therefore, in this paper, we provide a frontier method based on DEA to help the MTO manufacturer select the sourcing partners and determine the associated quantity allocation for each selected supplier.

For each potential sourcing part supplier, it is examined by estimating the processing speed, the available capacity and cost structure. When the information is obtained, a pool of part superior portfolios and order superior portfolios can be determined. Then we use the DEA technique to evaluate the portfolios according to the performance of two factors, shortage risk and the associated cost, and recommend the frontier ones to the MTO manufacturers.

The proposed method is not only used in the condition of a given due date, it can also be applied if the due date is not determined. Based on an estimated due date which the manufacturer is confident to achieve, there is a shortest due date which generates no portfolio at a certain service level by shortening the delivery date. The shortest due date will be beneficial to help the MTO manufacturer win the bid in a competitive environment.

Inevitably, this paper is limited and can be extended in several directions in further studies. First, as a successful evaluation technique, DEA can achieve excellent performance under complex conditions. For instance, DEA could solve the issues of missing-data or data inaccuracy. Second, the number of possible sourcing partners highly influences the method's working performance. We doubt that the processing speed may not be fast if the calculation is large and a better searching algorithm could be desired to improve the situation.

REFERENCES

Omitted