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Editor:
Gandhi Pawitan
Catharina B Nawangpalupi
Carles Sitompul
Giandi Kartasasmita

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Parahyangan Catholic University
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Abstract

Challenges facing small and medium enterprises are different than those facing larger corporations. However, all enterprises also share the same underlying problem that is fulfilling customers' demand. Indonesia has more than 50 millions small and medium enterprises, which is larger than the number of population in some countries. In some areas, these enterprises have formed some sort of clusters based on their operations and their geographical natures. In order to develop their operational efficiency, it is imperative that they form strategic relationships within each other. We attempt to conceptually model these relationships in term of supply chains. We then formulate some mathematical models in attempt to efficiently develop the supply chain planning model for small and medium enterprises.

Keywords: optimization, supply chain planning, small and medium enterprises

1. Introduction

Small and medium enterprises (SMEs) are facing underlying problems which are basically the same as any other enterprises, that is fulfilling customers’ demands. In the context of meeting customers demands, the
concept of supply chain is then introduced for small and medium enterprises. A supply chain is defined as a group of enterprises that works together to gain sustainable advantages through the process of fulfilling customer’s demand. A supply chain typically consists of a number facilities where raw materials, semi-finished products or finished products are acquired, transformed, stored or sold and transportation links that connects those facilities. A supply chain is often seen as a network where nodes represents facilities or enterprises and arcs that represent flow of goods, information and money. A typical supply chain consisting of vendors, manufacturers, distribution centers, and customers is depicted in Figure 1.

![Figure 1. A typical supply chain network](image)

There exists an extensive studies on supply chains. A google search using the phrase “supply chain” alone produces more than 120 millions entries. Interested readers are referred to Shapiro (2001) for further understanding in supply chains. Although there exists a large number of studies in the area of supply chains, there is still a lack of investigations for the purpose of small and medium enterprises. Challenges facing small and medium enterprises are different that those facing any large enterprises. For example, the quantity of distribution centers and transportation modes are often very limited. Furthermore, capacity constraints (both production and transports) have become the most imminent characteristic that distinguish SMEs and large enterprises. This paper proposes a supply chain planning model for small and medium enterprises where capacity constraints become very evident. The paper is written based on the following structure. Section 2 explains the conceptual framework and the problem description for the supply chain planning model in small and medium enterprises. In section 3, a mathematical model is developed for the supply chain planning where capacity is constrained. Section 4 summarizes some concluding remarks and suggestions for further studies.

2. Problem description

Assume that a manufacturer has two small and medium enterprises as its supplier, which can be seen in Figure 2. Supplier 1 and 2 are two small and medium suppliers which supply raw materials or products to a manufacturer. In the context of SMEs in Indonesia, this type of relations is very common among companies whose suppliers are SMEs. As a matter of fact, a manufacturer has very often more than two suppliers,
which are small and medium in size. To simplify the problem, we assume that a manufacturer has two suppliers. The generalization of this problem is actually straightforward.

Figure 2. A two-suppliers problem

Let us assume that the manufacturer is facing a stochastic demand which is stationaire and following a normal distribution with average $\mu$ and standard deviation $\sigma$. When demand information is transferred along the supply chain members, i.e. to the suppliers, it is then necessary for both suppliers to immediately plan their production in order to supply the needs of the manufacturer. Unfortunately, these information are not always available to suppliers. In many cases, suppliers receives this information only after the manufacturer places their orders. Thus, many SMEs in Indonesia are positioning their production strategy in a make-to-order (MTO) basis. Now, we let the production capacity of Supplier 1 and Supplier 2 denoted as $c_1$ and $c_2$, where $c_1 + c_2 > \mu$, otherwise the problem will not yield any feasible solutions. It is therefore necessary for the customer to have this capacity information beforehand.

Since demands facing the customer are stochastic, the manufacturer must places some safety stocks in order to meet its demand most of the time. Furthermore, some safety stocks must be placed on suppliers too because this demand uncertainty will be transferred along the supply chain members. Safety stocks are considered as a robust tool to help the supply chain dealing with demand uncertainty. The problem is then defined as to determine the number of safety stocks placed in front of all members in the supply chain. Bear in mind that productions in suppliers are constrained by some production capacities. Graves and Willems (2000) and Sitompul et al. (2008) have investigated this problem which is called the safety stock placement problem in supply chains. Graves and Willems (2000) studied the problem for a general type of network where capacity is unlimited. Sitompul et al. (2008) has investigated the same problem for capacitated supply chains but the network is still a linear type. To elaborate the problem, we propose a formulation for the capacitated supply chain, where the type of the network is depicted in Figure 2, which is a generalization from the linear type.

When demand is stochastic following a normal distribution with average $\mu$ and standard deviation $\sigma$, the safety stock is defined as:

$$SS = z_{1-\alpha} \sqrt{NRT}$$ ................................................................. (1)

where $z_{1-\alpha} = 2.33$ for a 1% of stockout probability and $NRT = \text{net replenishment time}$. Sitompul et al. (2008) suggested that the number of safety stock in a capacitated enterprises must be corrected by a certain factor, that is:
\[ \theta = 1 + 5.25e^{-5.25(\rho - 0.075)} \]  \hspace{1cm} (2)

where \( \rho = (c - \mu)/\sigma \) and
\( c \) = capacity,
\( \mu \) = average demand,
\( \sigma \) = standard deviation demand.

Because the problem has multiple suppliers, this correction factor must be applied to all suppliers. Rearranging the problem described in Figure 2, we now have two linear type of problems. The first linear type problem consists of Supplier 1 and the customer, while the second linear problem consists of Supplier 2 and the customer (see Figure 3).

![Figure 3. A two-linear type problem](image)

The reversed triangle shows the safety stock placed in four different places. The safety stock for the customer is then the summation of safety stock from both linear type problems. Assume that both suppliers received their raw materials from an abundant supply with lead times equal to zero (immediate replenishment). The customer must also fulfill its demand immediately. In other words, the lead time guaranteed by the manufacturer equals to zero. The production lead time for the manufacturer equals to \( T \) periods and the production (or preparation) times for Supplier 1 and Supplier 2 are denoted by \( t_1 \) and \( t_2 \) respectively. The holding costs for safety stocks at the manufacturer is denoted by \( H \) and the holding costs at Supplier 1 and Supplier 2 are denoted by \( h_1 \) and \( h_2 \) respectively. The concept of guaranteed service time as suggested by Graves and Willems (2000) can be applied in the context of many SMEs. Frequently, SMEs (suppliers) are bounded to supply their manufacturer using guaranteed service times. Let \( S_1 \) and \( S_2 \) denote the guaranteed service time from Supplier 1 and Supplier 2 respectively to the manufacturer. The guaranteed service time from the manufacturer to its customers equals to zero because the demand must be fulfilled immediately. The net replenishment time an enterprise is defined as:
\[ = \text{time to receive its material + production time - guaranteed service time} \]

The net replenishment time for Supplier 1 and Supplier 2 are then formulated as:
\[ \tau_1 = 0 + t_1 - S_1 \] \hspace{1cm} (3)
\[ \tau_2 = 0 + t_2 - S_2 \] \hspace{1cm} (4)

The net replenishment time for the manufacturer (\( R \)) for the first and second linear type problems are formulated as:
\[ R_1 = S_1 + T - 0 \] \hspace{1cm} (3)
\[ R_2 = S_2 + T - 0 \] \hspace{1cm} (4)
Because the problem is re-arranged into two linear type problems, it is therefore necessary to redistribute the demand to two suppliers. Assume that we use proportional redistribution, the average demand for Supplier 1 and Supplier 2 are defined respectively as:

\[
\mu_1 = \frac{c_1}{c_1 + c_2} \mu 
\]

\[
\mu_2 = \frac{c_2}{c_1 + c_2} \mu 
\]

These redistributions ensure that the demand are distributed proportionally according to the capacity constraints. The standard deviation of demand, however, cannot be treated equally as the average of the demand. The standard deviation are distributed according to the following equation:

\[
\sigma_1^2 + \sigma_2^2 = \sigma^2 
\]

Hence, the standard deviation of demand facing Supplier 1 and 2 are defined as:

\[
\sigma_1 = \frac{\sigma}{\sqrt{2}} 
\]

\[
\sigma_2 = \frac{\sigma}{\sqrt{2}} 
\]

We are now ready to formulate the problem as the problem of minimizing total costs subject to some restrictions.

3. Mathematical model

The safety stock placement problem can then be seen as the problem of minimizing total costs subject to some restrictions.

Minimize total costs: 

\[
z = (h_1 SS_1 + h_2 SS_2) + H (SSM_1 + SSM_2) 
\]

subject to:

\[
SS_1 = \theta_1 c_1 \sigma_1 \sqrt{T_1 - S_1} 
\]

\[
SS_2 = \theta_2 c_2 \sigma_2 \sqrt{T_2 - S_2} 
\]

\[
SSM_1 = \theta_{11} c_1 \sigma_1 \sqrt{T_1 + T} 
\]

\[
SSM_2 = \theta_{21} c_2 \sigma_2 \sqrt{T_2 + T} 
\]

\[
t_1 - S_1 \geq 0 
\]

\[
t_2 - S_2 \geq 0 
\]

\[
S_1, S_2 \geq 0 
\]

where \(\theta_{11}, \theta_{21}, \theta_{12}, \theta_{22}\) are the correction factors for Supplier 1, Supplier 2 and the manufacturer (both linear type problems) which can be calculated as in Equation (2). Equation (9) shows the total holding costs at suppliers and at the manufacturer. Equations (10) and (11) are used to define the quantity of safety stocks at Supplier 1 and Supplier 2 respectively. The safety stock at the manufacturer is defined from the two linear type problems as shown in Equations (12) and (13). Equation (14) and (15) ensures that the net replenishment time for each supplier is larger or equal to zero. The nonnegative restrictions ensures that the guaranteed service time is also larger or equal to zero. The safety stock placement problem can then be seen as the
problem to determine the guaranteed service time. These guaranteed service times ensure the supply chain meeting its customers demand through safety stock with minimum holding costs. This problem is naturally a nonlinear programming model.

4. Concluding remarks

This paper proposes a mathematical model for a supply chain planning for small and medium enterprises, in particular for the safety stock placement problems. The problem studied by Graves and Willems (2000) are extended in this paper in order to accommodate the fact that most SMEs have capacity constraints. A two suppliers problem are formulated as a non linear programming model. The implication of this model imposes that capacitated SMEs must strongly collaborate with the manufacturer in order to efficiently place their safety stock. In doing so, the manufacturer can be ensured regarding the guaranteed service time by its suppliers. Conceptually, collaborations in term of sharing information about the demand and the capacity will yield a win-win solution for all members in the supply chain. Suppliers which are small and medium enterprises and have very limited capacity can gain efficiency in term of holding stocks. In the same time, the manufacturer can fulfill its customer demands because the lead time to receives its material is more guaranteed. Further study is directed toward the evaluation of this model as well as extending the model to include the stochastic production lead times. Up to this point, we still assume that proportional redistribution is used. It is thus advisable to further investigate the optimal redistribution of demands among suppliers.

References