Multi-Sourcing and Quantity Allocation under Transportation Policies

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Abstract

Multi-sourcing, inventory, and transportation management are among the major levers of a supply chain. In this paper, we study the case of multi-sourcing problem by considering the transportation policies used between suppliers and a buyer. Thus, we propose a programming model that determines the optimal order quantities to allocate to the suppliers used, according to the direct or indirect shipment. The objective to minimize in the model is the total logistics cost which is composed of purchasing, inventory, and transportation costs. The constraints related to suppliers and buyer are considered. The model is illustrated with a comprehensive example.

Keywords: nonlinear programming, multi-sourcing, quantity allocation, transportation, simulation

1 Introduction

Transportation and sourcing from suppliers are among the main activities for a supply chain management and optimization. Indeed, the costs of raw materials and components account for 40 to 60% of production costs for most US manufacturers (Wadhwa and Ravindran, 2007), while the transportation cost accounts a large part of the total logistics cost. The literature is very abundant on the sourcing and supplier selection studies in terms of criteria, methods for measuring their performance, and strategies on mono versus multi-sourcing.

This paper also caters these issues, and studies the impact of transportation on the multi-sourcing process. Indeed, in that process, splitting orders across multiple suppliers will lead to smaller transportation quantities which will likely imply larger transportation cost. Moreover, transportation and inventory elements are highly interrelated and contribute mostly to the total logistics cost. Finally, transportation takes a great place in the current context of sustainable development.

The remainder of this paper is organized as follows. Section 2 presents relevant literature on the sourcing strategy. In Section 3, the mathematical model is described. Section 4 reports the results of computational experiments, based on simulations. The last section contains some concluding remarks.

2 Literature review

Sourcing strategy is one of the most critical activities in purchasing process. This strategy further includes the supplier selection problem, which is widely studied in the literature. It's a very complex process because it involves various conflicting criteria such as cost, quality, delivery, reputation, flexibility, production capacity, geographical location, relationship, etc.

Dickson (1966) was the first one to address this issue and has identified 23 different criteria by which purchasing managers have selected suppliers in various procurement environments. The problem is how to select suppliers that perform satisfactorily on the desired criteria. Based on a review of 74 papers published since 1966, Weber et al. (1991) have found that vendor selection is a multi-criteria decision making (MCDM). To solve that MCDM problem, the authors showed that the proposed approaches might be grouped into three categories, which are: linear weighting methods, mathematical programming models, and statistical/probabilistic approaches. Since that time, other methods in various research contexts such as supply chain design/management, agile manufacturing, and dynamic alliances appeared in the literature. For instance: Expert system (Zhao and Yu, 2011; Amindoust et al., 2012), multi-objective programming (Aguezzoul and Ladet, 2007; Amid et al., 2009; Jadidi et al., 2014), Data Envelopment Analysis (DEA) (Sevkli et al., 2003), Analytic Network Process (ANP) (Dargi et al., 2014), hybrid approach (Demirtas and Üstün, 2009; Haldar et al., 2012; Karsak and Dursun, 2014), etc. An analysis of these methods can be found in (Aguezzoul and Ladet, 2006; Ho et al., 2010; Chai et al., 2013; Aguezzoul, 2014).

As mentioned in (Aguezzoul, 2015), in these various approaches, the criteria relating to transportation like shipment cost, geographical location of supplier, etc. are considered in the outsourcing process only in an implicit manner. Moreover, the stocks in the entire transportation network linking buyer to suppliers is not evaluated. Finally, in the current context of sustainable development, environmental dimensions such as external transport costs that are related to air pollution, noise, congestion, accidents, etc., are rarely considered.

In this paper, we refer to the work cited in (Aguezzoul, 2015) by considering the particular case of transit via a single terminal. In addition, we study the case of several scenarios depending on whether or not the suppliers use the transit via the given terminal. The detail of the model is given in the following paragraph.

3 Model development

In this article, we consider the total logistics cost as the relevant criterion to minimize in the case of sourcing from several suppliers. Such suppliers have to establish a green supply chain. The total cost is the sum of purchasing, transportation, external shipment, and inventory costs, while capacity and quality of suppliers, and buyer's demand are formulated as constraints. The model aims to deduce the order quantity for each supplier, taking into account the transportation policies to put in place between each supplier and the buyer. The following notation and formulations to model this problem are:

n: number of suppliers,

D: buyer demand per unit time, assumed constant,

Q: ordered quantity to all suppliers in each period,

Q_i: ordered quantity to i^{th} supplier in each period,

A_i: ordering cost of i^{th} supplier per order, in each period,

P_i: unit purchase price of i^{th} supplier,

C_i: production capacity of i^{th} supplier,

q_i: rate of quality of i^{th} supplier

q_a: minimum rate of quality accepted by the buyer

r: inventory holding cost rate

d_i: distance between the i^{th} supplier and the buyer,

Cf_i: shipping cost per distance between the i^{th} supplier and the buyer,

Cv_i: shipping cost per load between the i^{th} supplier and the buyer.

Cex_i: external shipping cost between the i^{th} supplier and the buyer.

The decision variables for the model are:

- X_i: fraction of Q assigned to i^{th} supplier
- $Y_i = \begin{cases} 1 \ if \ X_i > 0 \ (i^{th} \ supplier \ is \ used) \\ 0 \ if \ X_i = 0 \end{cases}$

In addition, D/Q is the number of periods during the time considered. The total cost has the following form:

$$TC = \sum_{i=1}^{n} [DX_iP_i] + \left[D/Q \begin{pmatrix} d_iY_i(Cf_i + Cex_i) \\ +QX_iCv_i \end{pmatrix}\right] + [rP_iQX_i^2] \qquad (1)$$

- The first term in this function is the total purchasing cost. X_iD is the part of demand to assign to i^{th} supplier,
- The second term represents the total transportation cost. Cf is a fixed shipping cost which is independent of a load and includes cost of stop and cost per unit distance. Cv is a cost per load and it's independent of the distance covered. Cex is the external cost of transportation,
- The last term in the function is the total inventory cost. In a transportation network, total inventory includes loads that are waiting to be shipped from each supplier, and loads that are waiting to be used by the buyer. That supposes that each supplier produce items at a constant rate and the production planning is synchronized with that of transportation. The average time required to *i^th^* supplier to produce a shipment of size Q_i is Q_i/D. Each item in the load waits on average half of this time before being shipped $Q_i/2D$. After arriving, each item waits on average $Q_i/2D$ before being used. Thus, the average time spend by an item from i^{th} supplier to buyer is: Q_i/D.

Here, we use the Economic Order Quantity (EOQ) model which is widely used to calculate the optimal lot size to reduce the total logistics cost. EOQ is the value that cancels the derivation of TC:

$$EOQ = \sqrt{\frac{D\sum_{i=1}^{n} Y_i\, d_i(Cf_i + Cex_i)}{r\sum_{i=1}^{n} P_iX_i^2}} \qquad (2)$$

Thus, by replacing Q by EOQ in (1), the final expression of the total cost is:

$$TC = \sum_{i=1}^{n} DX_i(P_i + Cv_i) + 2\sqrt{Dr\left(\sum_{i=1}^{n} d_iY_i(Cf_i + Cex_i)\right)\left(\sum_{i=1}^{n} P_i\, X_i^2\right)} \qquad (3)$$

The mathematical formulation of the nonlinear programming model is given as follow:

$$Min(TC) = \sum_{i=1}^{n} DX_i(P_i + Cv_i) + 2\sqrt{Dr\left(\sum_{i=1}^{n} d_iY_i(Cf_i + Cex_i)\right)\left(\sum_{i=1}^{n} P_i\, X_i^2\right)} \qquad (4)$$

The mathematical formulation of the nonlinear programming model is given as follow:

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$$+2\sqrt{Dr\left(\sum_{i=1}^{n} d_i Y_i (Cf_i + Cex_i)\right)\left(\sum_{i=1}^{n} P_i X_i^2\right)} \quad (5)$$

S.T.

$$\begin{cases} X_i D \leq C_i & i = 1, n & (6) \\ \sum_{i=1}^{n} q_i X_i \geq q_a & & (7) \\ \sum_{i=1}^{n} X_i = 1 & & (8) \\ \epsilon Y_i \leq X_i \leq 1 & i = 1, n & (9) \\ Y_i = 0, 1 & i = 1, n & (10) \end{cases}$$

- Equation (5) represents the total cost TC to minimize and whose expression is given by (4).
- Constraint (6) represents the capacity restriction for each supplier.
- Constraint (7) is an aggregate performance measure for quality for all suppliers.
- Constraint (8) indicates that demand is placed with the set of n suppliers.
- Constraint (9) requires that an order be placed with a supplier if only it's used; ε is a positive number, slightly greater than zero.
- Constraint (10) imposes binary requirements on the decision variables Y_i.

4 Numerical example

4.1 Problem Data

In this section, we present a case study of three suppliers, denoted S1, S2 and S3, who have capacities limited. Two types of shipment are used: a TruckLoad (TL) and a Less than TruckLoad (LTL), characterized respectively by the shipping cost per load of 0€ and 0.05€, the shipping cost per distance of 1.32€/mile and 0.15€/mile, and the external cost per distance of 1.11€ and 1.07€. The demand of the buyer is 1000 per week, r=20%, and the minimum accepted rate of quality is 95%. Table 1 below contains other information on the suppliers. In these experiments, we take ε = 0.001 by supposing that 0.1% is the minimum percentage of the demand that the buyer will order to a supplier.

Table 1. Suppliers' information.

Suppliers	*S1*	*S2*	*S3*
Capacity	700	800	600
Rate of quality (%)	97	95	93
Unit purchase price (€)	9	7	5
Distance to buyer (miles)	100	150	200
Distance from suppliers to terminal (miles)	50	70	100

To solve the model, simulations are used. Each one corresponds to a scenario, which depends on the mode of transport (Tl or LTL) used between each supplier and the buyer. We then have the following eight scenarios:

- Scenario 1: Each supplier uses a TL.
- Scenario 2: S1 uses a LTL while each of S2 and S3 uses a TL.
- Scenario 3: S2 uses a LTL while each of S1 and S3 uses a TL.
- Scenario 4: S3 uses a LTL while each of S1 and S2 uses a TL.
- Scenario 5: each of S1 and S2 uses a LTL while S3 uses a TL.
- Scenario 6: each of S1 and S3 uses a LTL while S2 uses a TL.
- Scenario 7: each of S2 and S3 uses a LTL while S1 uses a TL.
- Scenario 8: Each supplier uses a LTL.

4.2 Computational Results

The results presented in table 2 bellow are generated on a personal Acer computer (Intel Core, 2.10 GHz) using Matlab software version 6.1.

Table 2. Computational results.

Scenario	*% of order quantities*			*Total cost (€)*
	X_1	X_2	X_3	
1	28	37	35	7964,14
2	30	34	36	7895,71
3	22	56	22	8088,12
4	28	42	30	8320,93
5	20	55	25	8081,67
6	29	37	34	7847,01
7	23	58	19	8169,99
8	26	54	20	8030,18

From these results, we can deduce the following remarks:

- This table gives the quantity allocation for the suppliers, and the total logistics cost, according to the transportation policy considered.

- The quantities to order to each of the three suppliers depend much of the scenario used, and therefore of the considered transport policy.
- Over 50% of the quantity is allocated to the supplier within scenarios 3, 5, 7 and 8. In these cases, transportation between S2 and buyer is done by a LTL.
- In all scenarios, the total cost is minimum (= 7847, 01) for scenario 6. In this case, each of S1 and S3 uses a LTL while S2 uses a TL. The order quantities in % for suppliers are respectively 29, 37, and 34.

5 Conclusions

Multi-sourcing strategy is one of the most critical activities of purchasing management in a supply chain. A review of literature on that field shows that there has been very little work that comprehensively examines the role of the transportation in this decision.

In this paper, a nonlinear programming approach is developed to determine the order quantities to allocate to the suppliers considered, taking into account the type of transportation, LTL or TL. To solve the model, simulations are used; each one corresponds to a given scenario related to a transportation policy used to carry the products bought from the suppliers to the buyer with an aim of minimizing total logistics cost. Thus, the buyer will have available several scenarios to make its procurement decisions.

One of the prospects for this work is to integrate the case where goods can be transhipped through intermodal freight transportation. In this case, the goods undergo at least three changes of the means of transportation between their origin and their destination. For example, in a road-rail combined transport, a shipment is first transported by truck to a given terminal. Then, it is transhipped from truck to train. At the other end of the transport chain, the shipment is transhipped from train to truck and delivered by truck to the receiver.

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