Effects of direct and intermodal transport on supplier selection: a multiobjective approach

Aicha Aguezzoul, Bahia Benchekroun, Pierre Ladet

EFFECTS OF DIRECT AND INTERMODAL TRANSPORT ON SUPPLIER SELECTION: A MULTIOBJECTIVE APPROACH

A. Aguezzoul [1,2], B. Benchekroun [3] and P. Ladet [2]
[1] Ibn Zohr University, ENCG, 37/S, hay salam, Agadir, Morocco
[2] LAG, BP 46, rue de la houille blanche, 38402, Saint Martin d'Hères cedex, France
[3] EMI, avenue Ibn sina, BP 765, agdal, Rabat, Morocco
(Aicha.aguezzoul, Pierre.Ladet)@inpg.fr, Bahia@emi.ac.ma

Abstract

The impact of transportation on the supplier selection has received a very scant attention in the literature. It induces a great limitation because 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 most to the total logistics costs. In this paper, we present a nonlinear multiobjective programming approach of selecting suppliers and allocating the order quantity among them, taking transportation into account. In our study, we consider the case where the product brought from selected suppliers can be shipped directly or via consolidation terminals to the buyer. Shipping via a terminal can incur an inventory holding cost. The model considers the total product cost and the lead-time as the criteria to minimize concurrently subject to suppliers and buyer constraints. The total cost is the sum of transportation, inventory and ordering costs. An evaluation of the model is presented under various scenarios.

Keywords

Nonlinear multiobjective model, Supplier selection, Consolidation terminal, Inventory

1. Introduction

In today's increasing competitive business world, the suppliers selection becomes the most critical activity of the purchasing function in a supply chain. On one hand, the cost of raw materials and component parts constitutes more than 40% of the total product cost and on the other hand, the supplier selection impacts the total performance of a firm.

The studies in that field show that this decision is a complex process involving multiple criteria such as procurement cost, product quality, delivery performance, etc. These criteria may vary depending on the type of product considered and are often in conflict with one another. For example, low prices can be offset by poor quality or delivery reliability. Therefore, the supplier selection is an inherently multiobjective decision. In 1966, Dickson [1] has identified at least 23 criteria in his empirical study in various vendor selection problems. Moreover, a review of 74 articles by Weber et al [2] gave similar results and showed also that several approaches have been suggested to take the multiobjective nature of the decision problem into account. However, that study identified very few articles which proposed mathematical programming techniques to analyze supplier selection decision. Over the past few years, other techniques were suggested in the literature. We can mention: interpretive structural modeling ([3]), expert system ([4]), data envelopment analysis ([5]; [6]), multi-objective programming ([7]), etc. Other models have been considered in [8]. However, the

transportation aspect is not considered explicitly in these techniques. This is a great limitation because 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 most to the total logistics costs: costs incurred in the suppliers while the products wait to be shipped, costs represented by the products in transit and costs incurred in the buyer while the products wait to be used. Finally, transportation has a direct impact on the lead-time, which affects the firm's total cycle time.

The most important articles that have addressed the problem of multi-sourcing, in particular dual sourcing and transportation are [9] and [11]. Hong et al [9], who have discussed reducing lot size in the just in time purchasing environment with multiple vendors. A nonlinear programming problem is formulated and the objective is to minimize the aggregate ordering and holding costs under delivery cost and quality constraints. Transportation cost is not formulated explicitly in the model. For multiple sourcing, the model gives the optimal selection of suppliers and the size of the split orders whereas, for the single sourcing, it determines the optimal number of deliveries. More recently, Tyworth et al [11] investigate the role of transportation in the single versus dual sourcing decision. They present a model, which minimizes the sum of purchasing, ordering, storage and transportation costs. No constraints are defined in the model. They demonstrated that dual supplier sourcing could yield savings under some conditions on supplier price, annual demand, lead-time performance and line-haul distance.

In these various research, stocks in the entire transportation network (suppliers, transit and buyer) are not clarified and the constraints related to transportation policy are not considered. The contribution of our paper is the integration of all these elements in the multi-objective programming (MOP) approach that we propose. The MOP model was first introduced in [12] as a technique for selecting vendors in procurement environment characterized by multiple conflicting criteria. In our case, we are especially interested in the type of shipping (direct or via terminals) used to move products from suppliers to buyer and its impact on the supplier selection. In this context, we present a nonlinear multiobjective programming approach (NMOP) to solve this problem. The model objective is to minimize the total cost and the lead-time criteria under suppliers and buyer constraints. The total cost includes transportation, ordering and inventory costs. The model simultaneously determines the optimal number of suppliers to employ and the order quantities to allocate to them, taking the transportation policy into account. The model is validated using a numerical example.

This paper is structured as follows. In the next section, we present the mathematical form of our model. In section 3, we give a solution methodology of the multiobjective model. Section 4 reports and discusses the computational results of the model. The final section contains some concluding remarks.

2. Model formulation

The buyer must make a choice of a set of potential suppliers, on the basis of criteria, which take transportation into account, namely total product cost and lead-time. The objectives to minimize simultaneously in the model are these two criteria. Total cost includes ordering, transportation and inventory costs subject to lead-time and capacity of each supplier; lead-time

imposed by the buyer and shipment type constraints. Moreover, we assume that the buyer'demand is known and constant and that the transportation capacity is unlimited.

The notation used in this paper is given below:

n: number of suppliers
D: unit time demand of buyer
Q: quantity ordered to all suppliers in each period
Q_i: quantity ordered to i^{th} supplier in each period
A_i: ordering cost per order, of i^{th} supplier
P_i: purchase price of i^{th} supplier
C_i: production capacity of i^{th} supplier
l_i: lead-time required by i^{th} supplier
T_{ij}: average transit time from i^{th} supplier to j^{th} terminal,
T_{j0}: average transit time from j^{th} terminal to buyer,
T_{i0}: average transit time from i^{th} supplier to buyer,
T_j: average transit time via j^{th} terminal,
L: lead-time imposed by the buyer,
r: holding rate of the buyer,
r_i : holding rate of i^{th} supplier,
rt_j: holding rate of j^{th} terminal,
rt_{ij}: in-transit holding rate from i^{th} supplier to j^{th} terminal,
rt_{j0}: in-transit holding rate from j^{th} terminal to buyer,
rt_{i0}: in-transit holding rate from i^{th} supplier to buyer,
Cf_{ij}: fixed shipping cost between i^{th} supplier and j^{th} terminal,
Cf_{j0}: fixed shipping cost between j^{th} terminal and buyer,
Cf_{i0}: fixed shipping cost between i^{th} supplier and buyer,
Cv_{ij}: variable shipping cost between i^{th} supplier and j^{th} terminal,
Cv_{j0}: variable shipping cost between j^{th} terminal and buyer,
Cv_{i0}: variable shipping cost between i^{th} supplier and buyer.

The decision variables for the model are:

X_i : fraction of Q assigned to i^{th} supplier

$$Y_i = \begin{cases} 1 \text{ if } i^{th} \text{ supplier is selected} \\ 0 \text{ otherwise} \end{cases}$$

$$Z_j = \begin{cases} 1 \text{ if } j^{th} \text{ terminal is used} \\ 0 \text{ otherwise} \end{cases}$$

$$W_{i0} = \begin{cases} 1 \text{ if direct shipment is used from } i^{th} \text{ supplier to buyer} \\ 0 \text{ otherwise} \end{cases}$$

$$W_{ij} = \begin{cases} 1 \text{ if shipment from } i^{th} \text{ supplier to buyer goes via } j^{th} \text{ terminal} \\ 0 \text{ otherwise} \end{cases}$$

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

$$TC = \left[\sum_{i=1}^{n}(D/Q)AY_i\right]+\left[\sum_{i=1}^{n}(r_i+r)X_i^2PQ/2\right]+\left[\sum_{i=1}^{n}DPX_i\left(rt_{i0}T_{i0}W_{i0}+\sum_{j=1}^{k}(rt_{ij}T_{ij}+rt_jT_j+rt_{j0}T_{j0})W_{ij}\right)\right]$$
$$+\left[\sum_{i=1}^{n}(D/Q)\left((Cf_{i0}Y_i+QX_iCv_{i0})W_{i0}+\sum_{j=1}^{k}(Cf_{ij}Y_i+Cv_{ij}X_iQW_{ij})Z_j\right)+\sum_{j=1}^{k}(D/Q)\left(Cf_{jO}+Cv_{jO}(\sum_{i=1}^{n}X_iQW_{ij})\right)Z_j\right] \quad (1)$$

The first term in this function is the total ordering cost. A_i is restricted to traditional (non-transportation) ordering and inspection cost elements. The second term represents the total inventory cost incurred while loads are waiting to be shipped from each supplier and while loads are waiting to be used by the buyer. The third term is the in-transit inventory cost incurred between suppliers, terminals (if they are used) and buyer. The last term is the total transportation cost, which takes into account the use or not of terminals. We use the modeling (Cf/Q + Cv) suggested in [13].

As Q is the optimum order quantity, it can be calculated by using the derivation of expression (1):

$$\frac{\partial TC}{\partial Q}=0\Rightarrow Q=\sqrt{\frac{2D\left(\sum_{i=1}^{n}(A_i+Cf_{i0}W_{i0}+\sum_{j=1}^{k}Cf_{ij}Z_j)Y_i+\sum_{j=1}^{k}Cf_{j0}Z_j\right)}{\sum_{i=1}^{n}X_i^2P_i(r+r_i)}}$$

By substituting for Q in expression (1), TC expression becomes:

$$TC = \sqrt{2D\left(\sum_{i=1}^{n}(A_i+Cf_{i0}W_{i0}+\sum_{j=1}^{k}Cf_{ij}Z_jW_{ij})Y_i+\sum_{j=1}^{k}Cf_{jO}Z_j\right)\left(\sum_{i=1}^{n}(r_i+r)X_i^2P_i\right)}$$
$$+\sum_{i=1}^{n}\sum_{j=1}^{k}DW_{ij}X_i\left(Cv_{ij}Z_j+P_i(rt_{ij}T_{ij}+r_jT_j+rt_{j0}T_{j0})\right)$$
$$+\sum_{i=1}^{n}DX_iW_{i0}(Cv_{i0}+rt_{i0}T_{i0}P_i)+\sum_{j=1}^{k}DCv_{jO}(\sum_{i=1}^{n}X_iW_{ij})Z_j \quad (1a)$$

An appropriate aggregate performance measure for delivery to the buyer is given by several authors ([14], [15], [16]) in the expression (1b) below:

$$LT = \sum_{i=1}^{n} l_i X_i \quad (1b)$$

This implies that the long lead-time of one supplier is compensated by the sort lead-time of other suppliers

The mathematical formulation of the nonlinear multi-objective program model (NMOP) is given as follow:

$$Min \quad Z = (TC, \ LT) \tag{1}$$

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$$\begin{cases} X_i D \le C_i & i = 1, n & (2) \\ \sum_{i=1}^{n} l_i X_i \le L & & (3) \\ \sum_{i=1}^{n} X_i = 1 & & (4) \\ \varepsilon Y_i \le X_i \le Y_i & i = 1, n & (5) \\ X_i \ge 0 & i = 1, n & (6) \\ W_{i0} + \sum_{j=1}^{k} W_{ij} = 1 & i = 1, n & (7) \\ W_{ij} \le Z_j & i = 1, n \quad j = 1, k & (8) \\ Y_i \ Z_j, \ W_{i0}, \ W_{ij} = 1, 0 & i = 1, n \quad j = 1, k & (9) \end{cases}$$

Equation (1) specifies the multiobjective function whose components expressions are given by equations (1a) and (1b). Constraints (2) represent the capacity restriction for each supplier. Constraint (3) is an aggregate performance measure for delivery for all suppliers. Constraint (4) indicates that demand is placed with the set of n suppliers. Constraints (5) require that an order is placed with a supplier if only he is selected; ε is a positive number, slightly greater than zero. Constraints (6) enforce the non-negativity restriction on the decision variables X_i. Constraints (7) and (8) indicate the use of a direct or indirect shipment and suppose that a supplier must not use more than one terminal. Constraints (9) impose binary requirements on the decision variables Y_i, Z_j, W_{i0} and W_{ij}.

3. Solution methodology

The multiobjective programming is often used to find a compromise solution, which simultaneously satisfy a number of design criteria. In solving the multiobjective programming problems, classical methods reduce them into a single objective of minimizing a weighted sum of deviations from goals. In our case and since the cost and lead-time criteria have different magnitude orders; we have normalized the objectives by using the absolute values of the relative variations of each objective compared to its goal. Thus, the multiobjective function (1) can be rewritten as:

$$Min \quad Z = \alpha \frac{\left| \begin{array}{l} \left(\sqrt{2D\left(\sum_{i=1}^{n} (A_i + Cf_{i0}W_{i0} + \sum_{j=1}^{k} Cf_{ij}Z_j W_{ij})Y_i + \sum_{j=1}^{k} Cf_{j0}Z_j \right)\left(\sum_{i=1}^{n} (r_i + r)X_i^2 P_i \right)} \right. \\ + \sum_{j=1}^{k} DCv_{j0}\left(\sum_{i=1}^{n} X_i W_{ij} \right)Z_j + \sum_{i=1}^{n}\sum_{j=1}^{k} DW_{ij}X_i\left(Cv_{ij}Z_j + P_i(rt_{ij}T_{ij} + r_j T_j + rt_{j0}T_{j0}) \right) \\ \left. + \sum_{i=1}^{n} DX_i W_{i0}(Cv_{i0} + rt_{i0}T_{i0}P_i) \right) - G1 \end{array} \right|}{G1}$$
$$+ (1-\alpha)\frac{\left| \sum_{i=1}^{n} l_i X_i - G2 \right|}{G2}$$

This equation is a single objective function and our NMOP can be solved as a single objective optimization problem subject to constraints (2)-(9). G1, G2, α and (1-α) are respectively the cost, lead-time goals and the weighting factors for the absolute values of the relative variations of each criterion.

To find G1, we solve the model in section 2 by considering the cost as the only objective function (Z = TC), and we do the same thing for G2 (Z = LT).

The next section presents a numerical example to evaluate the model. All results presented are generated on a Compaq PC (Intel Pentium IV, 2.40 GHz) using Matlab version 6.5, a high-performance language that offers the optimization Toolbox as *fmincon.* This function finds a constrained minimum of a scalar function of several variables starting at an initial estimate. This is generally referred to as constrained nonlinear programming.

4. Numerical example

We study the case of three suppliers and a single terminal. In this case, we study various options; each one depends on the use of direct or indirect shipment.

We suppose that the suppliers use one of the two mode of transport: TL or LTL, which are respectively a truckload (TL) and a less than truckload (LTL); characterized respectively by the in-transit holding rate 12% and 10%, the variable shipping cost 0 and 0.05 and the fixed shipping cost 1.32$/mile and 0.15$/mile. The demand of the buyer is 1000 per week, r=20%, the distance from three buyer to the terminal is 100 miles, the maximum accepted lead-time is 2 days, the ordering, the purchasing costs and the holding rate of each supplier are respectively 10$, 5$ and 20%. In our experiments, we take ε=0.001.

Table 1 below contains other information on the suppliers, according to whether they use direct or indirect shipment.

	Supplier 1	Supplier 2	Supplier 3
Capacity	800	700	600
Distance to buyer (miles)	100	150	200
Distance from suppliers to terminal (miles)	50	70	100
Lead time offered by suppliers (days)	1.25	1.5	1.75
Transit time by direct shipment (weeks)	0.06	0.09	0.11
Transit time from suppliers to terminal (weeks)	0.03	0.04	0.06
Transit time from terminal to buyer (weeks)	0.14		

Table 1. Suppliers information

Table 2 below gives the eight options and the values of G1 and G2 for each scenario:

	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 8
W11	0	1	0	0	1	1	0	1
W21	0	0	1	0	1	0	1	1
W31	0	0	0	1	0	1	1	1
Scenario 1	G1 = 1349, G2 = 1.30							
Scenario 2	G1 = 1256, G2 = 1.30							
Scenario 3	G1 = 1371, G2 = 1.35							
Scenario 4	G1 = 1431, G2 = 1.58							

Table 2. G1 and G2 values for options and scenarios

By considering these values, table 3 summarizes the results of the NMOP. In our experiment, we vary the values of α from 0 to 1 with a step of 0.1. Usually, this factor is fixed by the decision maker, which makes the method subjective to the user.

Weight (α)	X1	X2	X3	Q	Transportation cost	In transit inventory cost	Inventory cost of buyer	Total cost	Total lead-time	Z*	Option
	Scenario 1										
1	0.34	0.33	0.33	693	491	374	231	1349	1.50	0	8
0.9	0.425	0.321	0.255	841	580	166	293	1349	1.46	0.012	4
0.8	0.428	0.336	0.236	836	582	160	294	1349	1.45	0.023	4
0.7	0.426	0.401	0.173	721	544	247	268	1349	1.44	0.032	7
0.6	0.426	0.363	0.210	829	586	153	297	1351	1.45	0.046	4
0.5	0.495	0.344	0.161	705	553	226	274	1349	1.42	0.045	7
0.4	0.567	0.293	0.140	673	574	204	287	1375	1.39	0.051	7
0.3	0.695	0.287	0.018	585	651	163	331	1501	1.33	0.050	7
0.2	0.800	0.190	0.010	535	705	132	362	1588	1.30	0.037	7

0.1	0.800	0.190	0.010	535	705	132	362	1588	1.30	0.019	7
0	0.800	0.190	0.010	535	705	132	362	1588	1.30	0	7
	Scenario 2										
1	0.508	0.492	0	583	566	90	292	1256	1.37	0	1
0.9	0.513	0.487	0	583	566	90	292	1256	1.37	0.006	1
0.8	0.521	0.479	0	583	566	89	292	1256	1.37	0.011	1
0.7	0.530	0.470	0	582	567	89	292	1257	1.37	0.016	1
0.6	0.542	0.458	0	581	568	88	293	1259	1.36	0.021	1
0.5	0.560	0.440	0	579	570	88	294	1262	1.36	0.026	1
0.4	0.708	0.292	0	461	534	159	271	1256	1.32	0.011	3
0.3	0.756	0.244	0	445	551	145	281	1280	1.31	0.012	3
0.2	0.800	0.200	0	428	569	132	291	1307	1.30	0.008	3
0.1	0.800	0.200	0	428	569	132	291	1307	1.30	0.004	3
0	0.800	0.200	0	428	569	132	291	1307	1.30	0	3
	Scenario 3										
1	0.510	0	0.490	472	501	376	236	1371	1.50	0	6
0.9	0.524	0	0.476	472	502	375	237	1371	1.49	0.010	6
0.8	0.543	0	0.457	471	503	374	273	1373	1.48	0.020	6
0.7	0.568	0	0.432	468	505	374	238	1377	1.47	0.029	6
0.6	0.601	0	0.399	463	510	372	241	1387	1.45	0.036	6
0.5	0.756	0	0.244	479	595	151	302	1371	1.37	0.008	4
0.4	0.800	0	0.200	461	616	136	314	1401	1.35	0.009	4
0.3	0.800	0	0.200	461	616	136	314	1401	1.35	0.007	4
0.2	0.800	0	0.200	461	616	136	314	1401	1.35	0.004	4
0.1	0.800	0	0.200	461	616	136	314	1401	1.35	0.002	4
0	0.800	0	0.200	461	616	136	314	1401	1.35	0	4
	Scenario 4										
1	0	0.506	0.494	500	530	382	250	1431	1.62	0	7
0.9	0	0.512	0.488	500	530	382	250	1431	1.62	0.003	7
0.8	0	0.520	0.480	499	530	382	250	1432	1.62	0.005	7
0.7	0	0.530	0.470	499	531	381	250	1432	1.62	0.008	7
0.6	0	0.544	0.456	498	532	381	251	1434	1.61	0.010	7
0.5	0	0.563	0.437	496	533	380	252	1438	1.61	0.012	7
0.4	0	0.593	0.407	491	538	380	254	1446	1.60	0.013	7
0.3	0	0.680	0.320	561	632	200	317	1483	1.58	0.011	4
0.2	0	0.680	0.320	561	632	200	317	1483	1.58	0.007	4
0.1	0	0.680	0.320	561	632	200	317	1483	1.58	0.004	4
0	0	0.700	0.300	553	639	194	321	1493	1.58	0	4

Table 3. Computational results of the NMOP

From this table, we can deduce the following remarks:

- For each option, the results illustrate that varying the weights of the criteria will result in different suppliers being selected with varying order quantities. Indeed, for options 1, the buyer will choose suppliers 1 and 2 if α varies from 0.5 to 1. For option 3, the buyer will select the same suppliers if α varies from 0.4 to 0. For option 4, the choice will relate to all suppliers if α takes values 0.9, 0.8 or 0.6, suppliers 1 and 3 if α varies from 0 to 0.5 and suppliers 2 and 3 if α varies from 0 to 0.3. For option 6, the buyer will choose suppliers 1 and 3 if α varies from 0.6 to 1. Finally, for scenario 7, the buyer will select all suppliers if α varies from 0 to 0.5 and if α takes value 0.7 and suppliers 2 and 3 if α varies from 0. 4 to 1. For options 2 and 5, no selection of suppliers is considered. For option 8, the choice will relate to all suppliers.
- The transportation cost is minimum for option 8 of scenario 1. In this case, all suppliers use shipment via consolidation terminal to move product to buyer. In the same way, the inventory cost of buyer is minimum. However, the in-transit inventory cost is maximum because of the time spent in transit and in the change of means of transport in the terminal.
- For a given value of α, example α=0.5, the minimum of all the Z^* is reached for option 4 of scenario 3 (0.008). The buyer will choose suppliers 1 and 3. In this case, supplier 1 uses direct shipment while supplier 3 uses shipment via the terminal. The transportation cost is important (595) and the optimum order allocations assigned to each supplier are respectively, in proportion 0.756 and 0.244. The optimum order quantity is 479 and the order quantities, which should be purchased from suppliers, respectively are 362 and 117 for each of the two periods because there are D/Q (=2.088) periods. At the third period, the buyer may order the remaining quantities to buyer 1 (42) to satisfy the demand.

4. Conclusion

In a multiple sourcing network, the buyer has to employ more suppliers concurrently. In this case, several problems arise such as the determination of the optimal number of suppliers and the portion of the order to allocate to each one.

In reviewing the literature on this area, we note that there has been very little work that comprehensively examines the role of the transportation in this selection.

In this research, we have developed and demonstrated the use of a multiobjective programming approach for improving the impact of transportation in supplier selection problem. The proposed approach is likely to find multiple solutions to the problem, each corresponding to a different setting of the weight factor.

The model takes into account the type of shipment used to move the products from selected suppliers to the buyer and our experiment results indicate that the shipping via consolidation terminals can reduce total cost. In the same way, the costs of transportation and inventory of buyer are reduced, thus compensating for the important cost of in-transit inventory.

The proposed comprehensive approach would help purchasing managers in selecting the right suppliers to employ and the transportation policy to use according to the weight factor assigned to each goal. Usually, this factor is fixed by the decision maker, which makes the method subjective to the user.

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