A Multi-objective Model for Supplier Selection with Multi-products in terms of Discount and Currency Exchange Rates

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Abstract

Supplier selection problem is one of the most important activities of purchasing managers in a supply chain. In this paper, supplier selection problem has been investigated with regard to currency fluctuation and price discounts. And for this purpose, a multi-objective model is provided that includes minimization of supplier management costs, purchase price, transportation cost, cost of quality control, and defective rates. The proposed model is capable of optimizing the supply costs, defective rates. In order to validate the proposed model, numerical examples are presented and some computational results are reported.

Keywords: supplier selection, allocation of orders, multi-objective programming, volume discount**.**

Introduction

The problem studied in this research is the case of a global company that wants to buy multiple materials from multiple suppliers located around the world. However, some of the suppliers may not provide all required items to the buyers. Suppliers are selling materials in their local currency. We show the sets of suppliers and buyer's sites with I and J respectively. Supplier selection decisions are made usually in long-term horizons of one to three years. Due to the problem being addressed, it includes inventory cost and currency fluctuation that we considered it in a multi-period situation. Purchasing managers should determine the suppliers to be selected and their orders. Total order quantity from material type p from supplier i is denoted by Q_{ip}. Depending on the total order quantity suppliers, you offer price discounts. To calculate the total purchase price, all prices must be converted to a standard currency unit, which is usually considered the standard currency of the buyer company. Currency exchange rates are usually related to currency fluctuations over time; it is difficult for the buyer to predict the long-term fluctuations. In this paper, the forecasts made by the Royal Bank of Canada will be used for the currency exchange rates- which are stated seasonally and are different in each period.

Supplier selection problem

Most articles of supply chain management from 1990 onwards, consider the relationship between buyer and seller and supplier selection criteria. Dickson was one of the first people who studied this. Narasimhan et al. (2006), provided multi-objective programming model for dealing with the problem of supplier selection in multi-products environment and in terms of discounts; they used bidding mechanism for selection of suppliers (Narasimhan et al. 2006). Jadidi, et al. (2008), provided an integrated multi-objective model and fuzzy TOPSIS for supplier selection problem. The purpose of this model is to minimize the total cost, the total purchase amount, and the returned items so that capacity constraints and demand are satisfied. In this research, a multi-objective function is intended for problem solving in multi-product environment (Jadidi et al. 2008). Ozkok and Tiryaki presented a compensatory fuzzy approach to multi-objective linear supplier selection problem with multiple-item in which fuzzy AND operator is used (Ozkok & Tiryaki 2011). Amid et al. (2011), provided a max-min weighted objective model for supplier selection in a supply chain. In this research, they used analytic hierarchy process to determine the weight of criteria. The proposed model helps to decider in an ordering allocation to each supplier (Amid et al. 2011). Kenarroudi, (2012) provided an integrated approach of fuzzy analytic hierarchy process and fuzzy multi-objective mixed integer linear programming - in the multi-product and multi periodically environment with discounts. In the first stage, qualitative and quantitative criteria were evaluated using the analytic hierarchy process. And in the second step, using a multi-objective integer programming model in a fuzzy environment, the supplier selection began (Kenarroudi 2012). Jadidi, et al. (2014) presented a multi-objective optimization model for supplier selection, in which price, rejected rate and on-time delivery are different objective functions considered (Jadidi et al. 2008). Kilic; (2013) provided an integrated approach which consists of fuzzy TOPSIS and mixed integer linear programming with multi-product and multi-periodic to select the best supplier (Kilic 2013). Hammami et al. (2014) presented a scenario based on stochastic model, considering discounts and currency fluctuation with multi-period for supplier selection which consist of management cost, purchasing price, transportation cost, and inventory cost (Hammami et al. 2014).

Proposed model

We modeled supplier selection problem as a multi-objective mixed integer programming. Important decisions that must be taken in this context are the selection of suppliers and the amount of purchase from each during the planning horizon. The objective functions minimize the total cost of logistics, and supply and quality control also minimize the defective rate. In the following section, we introduce the variables and parameters of the model.

I: Set of potential suppliers
J: Set of buyer sites in different regions of the world
T: Planning period
P: Set of raw materials to buy

Variables:

q_{ijp}^{t}Purchase amount of product type p by site j from buyer i in period t.
Y_{ip}: Binary variable, Y_{ip}=1 if i'th supplier is selected to provide p'th material otherwise Y_{ip}=0
a_{ip}^{n}: Binary variable, a_{ip}^{n}=1 if the purchased amount of p'th material from i'th supplier falls in n'th discount interval, otherwise a_{ip}^{n}=0.
S_{jp}^{t}: The amount of p'th material kept in the j'th site of the buyer company in t'th period.
x_{ijp}^{tn}: The purchase amount of p'th material by buyer j'th site from i'th supplier in t'th period which falls in n'th discount interval.

Parameters:
MC_{ip}: Supplier i'th management costs for p'th product.
TC_{ijp}: Unit transportation cost of p'th material from the supplier I'th location to buyer j'th site.
IC_{jp}^{t}: Unit inventory cost of p'th material in the buyer j'th site in t'th period.
D_{jp}^{t}: The demand for p'th product by buyer j'th site in period t.
W_{ijp}^{t}: Quality control unit cost of p'th material from i'th supplier which whould be purchased by buyer's j'th site in t'th period.
Z_{ijp}^{t}: Percent of defective of p'th material purchased from i'th supplier which have been detected in j'th site in t'th period.
α_{i}^{t}: Currency exchange rate of supplier i'th currency to the buyer currency.
N_{ip}: Number of discount intervals offered by the i'th supplier to provide p'th material.
U_{ip}^{n}: Unit purchase price of p'th material of i'th supplier which falls in n'th discount interval (which calculated in i'th supplier currency).
ψ: A positive very large number.
Q_{ip}: The total requested amount of p'th material from i'th supplier.
L_{ip}^{t}: Supplier i'th capacity to supply p'th material i in t'th period.
A_{ip}^{n}: The lower limit of the total amount of purchase for p'th material from supplier i over the planning horizon to get a discounted price corresponding to n'th interval.
TQC: The cost of quality control for all material types authorized by the buyer during the planning horizon.
TE: The total amount of defective materials authorized by the purchaser during the planning horizon.

The first objective function is the sum of the costs of supplier management, purchasing price, transportation costs and the cost of holding inventory. Except for the purchase price, all costs are expressed in the reference currency. MC_{ip} is charged once the supplier i who provide p'th material is selected $(Y_{ip}=1)$. The total management cost for all suppliers selected to supply all kinds of materials of formula $\sum_{i\in I}\sum_{p\in P} MC_{ip}$ is calculated. The unit purchasing price of p'th material supplier i depends on the considered interval of supplier i's discount. In terms of currency fluctuation, the purchase price of purchase amount which is expressed to the i'th supplier currency is $(\sum_{n=1}^{N_{ip}} a_{ip}^{n} U_{ip}^{n}) q_{ijp}^{t}$; which is convertible to buyer reference currency to $\alpha_{i}^{t}\left(\sum_{n=1}^{N_{ip}} a_{ip}^{n} U_{ip}^{n}\right) q_{ijp.}^{t}$ Hence the total cost of purchase is equal to

$\sum_{j\in J}\sum_{i\in I}\sum_{t=1}^{T}\sum_{p\in P}\alpha_i^t(\sum_{n=1}^{Nip}a_{ip}^{n}U_{ip}^{n})q_{ijp}^{t}$. Unit transportation cost of p'th material from i'th supplier place to j'th site of buyer in period t is equal to $TC_{ijp}q_{ijp}^{t}$. So the total cost of transportation is equal to $\sum_{j\in J}\sum_{i\in I}\sum_{t=1}^{T}\sum_{p\in P}TC_{ijp}q_{ijp}^{t}$. The mean level of p'th material in j'th site of the buyer in period t is equal to $\frac{S_{jp}^{t}+S_{jp}^{(t+1)}}{2}$. So the inventory cost of materials is calculated by $\frac{S_{jp}^{t}+S_{jp}^{(t+1)}}{2}$. In this research, for simplicity of calculation the cost of inventory holding is considered $IC_{jp}^{t}S_{jp}^{t}$. So the first objective function is formulated as follows:

$$\text{Min } Z_1=\sum_{i\in I}\sum_{p\in P}MC_{ip}\,Y_{ip}+\sum_{j\in J}\sum_{i\epsilon P}\sum_{t=1}^{T}\sum_{p\in P}\alpha_i^t\left(\sum_{n=1}^{n=N_{ip}}U_{ip}^{n}a_{ip}^{n}\right)q_{ijp}^{t}+\sum_{j\in J}\sum_{i\in I}\sum_{t=1}^{T}\sum_{p\in P}TC_{ijp}q_{ijp}^{t}+\sum_{j\in J}\sum_{t=1}^{T}\sum_{p\in P}IC_{jp}^{t}S_{jp}^{t} \qquad (1)$$

The second objective function is the sum of all type of materials quality control cost in all sites of the buyer which purchased from all suppliers in the planning horizon; it is formulated as below:

$$\text{Min } Z_2=\sum_{j\in J}\sum_{i\in I}\sum_{t=1}^{T}\sum_{p\in P}W_{ijp}^{t}q_{ijp}^{t} \qquad (2)$$

The third objective function is the minimization of defect rate of all type of materials purchased from all suppliers in time horizon and detected in all sites of the buyer and formulated as below:

$$\text{Min } Z_3=\sum_{j\in J}\sum_{i\in I}\sum_{t=1}^{T}\sum_{p\in P}Z_{ijp}^{t}q_{ijp}^{t} \qquad (3)$$

The (1) objective function is nonlinear. For simplicity of calculation, we converted it to an equivalence linear objective function. In order to linearize, we define a non-negative variable-($X_{ijp}^{tn}=a_{ip}^{n}\times q_{ijp}^{t}$), so the (1) objective function would be converted to a linear objective function as follows:

$$\text{Min } Z_1=\sum_{i\in I}\sum_{p\in P}MC_{ip}\,Y_{ip}+\sum_{j\in J}\sum_{i\epsilon P}\sum_{t=1}^{T}\sum_{p\in P}\alpha_i^t\left(\sum_{n=1}^{n=N_{ip}}U_{ip}^{n}X_{ijp}^{tn}\right)+\sum_{j\in J}\sum_{i\in I}\sum_{t=1}^{T}\sum_{p\in P}TC_{ijp}q_{ijp}^{t}+\sum_{j\in J}\sum_{t=1}^{T}\sum_{p\in P}IC_{jp}^{t}S_{jp}^{t} \qquad (4)$$

To ensure that the above equality, ($X_{ijp}^{tn}=a_{ip}^{n}\times q_{ijp}^{t}$) is true, three constraints are added to constraints of the model in which ψ is a sufficient large number.

$$X_{ijp}^{tn} \leq q_{ijp}^{t} \qquad i\in I,\ j\in J,\ 1\leq t\leq T, p\in P,\ 1\leq n\leq N_{ip} \qquad (5)$$

$$X_{ijp}^{tn} \leq \Psi a_{ip}^{n} \qquad i\in I,\ j\in J, 1\leq t\leq T,\ p\in P,\ 1\leq n\leq N_{ip} \qquad (6)$$

$$X_{ijp}^{tn} \geq q_{ijp}^{t}+\Psi(a_{ip}^{n}-1) \qquad i\in I,\ j\in J,\ 1\leq t\leq T,\ p\in P,\ 1\leq n\leq N_{ip} \qquad (7)$$

according to constraints (8) to (9), the total amount of p'th materials purchased from i'th supplier ($\sum_{j\in J}\sum_{t=1}^{T} q_{ijp}^{t}$) must be equal to the total allocated value of p'th material to i'th supplier. If i'th supplier is selected to provide p'th material (Y_{ip}=1), then the requested value of p'th material from i'th supplier by all sites of buyer company in each period should not be greater than supplier i'th capacity for providing p'th material in each period t.

$$Q_{ip} = \sum_{j\in J}\sum_{t=1}^{T} q_{ijp}^{t} \qquad i\in I,\ p\in P \qquad (8)$$

$$\sum_{j\in J} q_{ijp}^{t} \leq L_{ip}Y_{ip} \qquad i\in I,\ 1\leq t\leq T,\ p\in P \qquad (9)$$

In order to obtain the unit price of p'th material associated with the discount interval n from supplier i, the total purchased quantity (Q_{ip}) must satisfy $A_{ip}^{n}\geq Q_{ip}\leq A_{ip}^{n+1}$. Recall for the first discount interval (n=1), the parameter $A_{ip}^{1}=0,\ \forall i\in I$. Only one discount interval n can be selected for each supplier i to provide each type of material. Since we minimize the purchasing cost in the first and second objective functions, the model will try to get the most profitable discount interval. Therefore, discount constraints can be formulated as follows:

$$a_{ip}^{n}A_{ip}^{n}\leq Q_{ip} \qquad i\in I,\ p\in P,\ 1\leq n\leq N_{ip} \qquad (10)$$

$$\sum_{n=1}^{N_{ip}} a_{ip}^{n} = 1 \qquad i\in I,\ p\in P \qquad (11)$$

According to constraints (12) to (14) in buyers site j in period t (t<T) for each material p, the sum of the stock at the beginning of period t (S_{jp}^{t}) and the total quantity received in period t ($\sum_{i\in I} q_{ijp}^{t}$) is equal to the sum of the stock at the beginning of period t+1 (S_{jp}^{t+1}) and the demand of period t (D_{jp}^{t}). The inventory levels at the beginning of the planning horizon are null as given in constraints. No inventories are kept at the end of the last period (t=T).

$$s_{jp}^{1}=0 \qquad j\in J,\ p\in P \qquad (12)$$

$$s_{jp}^{t}+\sum_{i\in I} q_{ijp}^{t} = s_{jp}^{(t+1)} + D_{jp}^{t} \qquad j\in J,\ 1\leq t\leq T\text{-}1,\ p\in P \qquad (13)$$

$$s_{jp}^{T} + \sum_{i \in I} q_{ijp}^{T} = D_{jp}^{T} \qquad j \in J,\ p \in P \qquad (14)$$

The cost of quality control in the time horizon for all products supplied by all suppliers in all sites should not be greater than the total quality control cost (TQC). The TQC parameter is determined by the purchasing manager. Also, the defective rate of all kinds of materials provided by different suppliers in time horizon in all sites of buyers should not be greater than total defective rate (TE) which is determined by buyer.

$$\sum_{j \in J} \sum_{i \in I} \sum_{t=1}^{T} \sum_{p \in P} W_{ijp}^{t} q_{ijp}^{t} \le TQC \qquad (15)$$

$$\sum_{j \in J} \sum_{i \in I} \sum_{t=1}^{T} \sum_{p \in P} Z_{ijp}^{t} q_{ijp}^{t} \le TE \qquad (16)$$

$$Y_{ip} \in \{0,1\} \qquad i \in I,\ p \in P \qquad (17)$$

$$a_{ip}^{n} \in \{0,1\} \qquad i \in I,\ p \in P,\ 1 \le n \le N_{ip} \qquad (18)$$

$$Q_{ip} \in R^{+} \qquad i \in I,\ p \in P \qquad (19)$$

$$q_{ijp}^{t} \in R^{+} \qquad j \in J,\ i \in I,\ 1 \le t \le T,\ p \in P \qquad (20)$$

$$s_{jp}^{t} \in R^{+} \qquad j \in J,\ 1 \le t \le T,\ p \in P \qquad (21)$$

$$X_{ijp}^{tn} \in R^{+} \qquad j \in J,\ i \in I,\ 1 \le t \le T,\ p \in P,\ 1 \le n \le N_{ip} \qquad (22)$$

4. Computational results

In order to show the validity of the proposed model, we have solved it by an example using GAMS software. The computational experiments conducted with the proposed mathematical model are inspired from the case study presented by (Hammami et al. 2014). The structure of this case study and the parameters used are based on a realistic problem faced by a US automotive manufacturer. It concerns the provisioning of two assembly plants with a single common part. One plant is located in Detroit, Michigan, and the second is located in Russelsheim, Germany. Considering the demand at each plant, American dollar is considered as the reference currency. Table 1 shows the average unit price offered by any supplier in local currency and in dollar. Currency exchange rates are shown in Table 2. Also supplier management costs in America dollars are shown in table 1. Shanghai is a cheaper supplier, but is expensive in management costs. Note that the cheapest supplier (Shanghai) has the lowest capacity.

Table 1. Suppliers data.

	Unit base price		Unit base price in USD		Management cost	
Supplier	Product 1	Product 2	Product 1	Product 2	Product 1	Product 2
Cleveland	22 USD	18 USD	22	18	37500	50000
Tokyo	1575 JPY	1275 JPY	21	17.30	37500	50000
Shanghai	107.1 CNY	85 CNY	17	14	150000	200000
Madrid	18.9 EUR	15.12 EUR	25	20	37500	50000

Parts are shipped under a multi-modal transportation format that might include truck. rail, or ship. Unit cost of transportation are listed in Table 2. These fees are based on the distance traveled in each shipping method, and standard costs are calculated.

Table 2. Unit transportation costs (USD).

	Detroit		Russelsheim	
Supplier	Product 1	Product 2	Product 1	Product 2
Cleveland	0.180	0.200	3.344	3.700
Tokyo	4.400	4.800	7.388	7.800
Shanghai	4.930	5.200	6.974	7.200
Madrid	3.316	3.500	1.312	1.500

Inventory costs of materials at various sites are shown in Table 3.

Table 3 Unit holding costs (USD).

Buyer sites	Detroit		Russelsheim	
Time periods	Product 1	Product 2	Product 1	Product 2
Period 1	2.56	2.85	2.78	3.10
Period 2	2.56	2.85	2.78	3.10
Period 3	2.56	2.85	2.78	3.10
Period 4	2.56	2.85	2.78	3.10

Demands for various products of different sites are shown in Table 4.

Table 4 Demand for different sites products.

Buyer sites	Detroit		Russelsheim	
Time periods	Product 1	Product 2	Product 1	Product 2
Period 1	271125	379575	180750	253050
Period 2	271125	379575	180750	253050
Period 3	271125	379575	180750	253050
Period 4	271125	379575	180750	253050

Capacities of suppliers are shown in Table 5.

Table 5 different suppliers capacity .

Time periods		Cleveland	Tokyo	Shanghai	Madrid
Period 1	Product 1	247600	247600	139200	247600
	Product 2	350000	350000	220000	350000
Period 2	Product 1	247600	247600	139200	247600
	Product 2	350000	350000	220000	350000
Period 3	Product 1	247600	247600	139200	247600
	Product 2	350000	350000	220000	350000
Period 4	Product 1	247600	247600	139200	247600

Product 2	350000	350000	220000	350000

Exchange rates forecasts are obtained from financial market, which are reported by Royal Bank of Canada. These forecasts are shown in Table 6.

Table 6 Exchange rates baseline forecasts .

Time periods	USD/EUR	USD/JPY	USD/CNY
Period 1	0.752	75	6.30
Period 2	0.763	76	6.30
Period 3	0.781	73	6.20
Period 4	0.787	71	6.10

We hypothesized that suppliers proposed quantity discount schedule with three intervals for each type of material. In Table 7, the range of discounts and the discount rates are given. These discount rates are used to calculate unit purchasing price of the materials. For example, the proposed unit price for the material which is provided by Cleveland supplier becomes $21.34 if the total order quantity over the planning horizon is larger than 500,000 units.

Table 7 Discount schedule for the different suppliers.

	A_{ip}^{n}		Quantity		Discount (%)
n	*Product 1*	*Product 2*	*Product 1*	*Product 2*	
1	0	0	0 to under 300000	0 to under 400000	0
2	300000	400000	300000 to under 500000	400000 to under 700000	1
3	500000	700000	500000 and over	700000 and over	3

Unit quality control costs of materials of each site purchased from each suppliers are different in time horizon. and are given in Table 8.

Table 8 Unit quality control costs.

	suppliers	*Cleveland*		*Tokyo*		Shanghai		Madrid	
periods		*product 1*	*Product 2*	*Product 1*	*Product 2*	*Product* 1	*Product* 2	*Product* 1	*Product* 2
Period 1	Detroit	0.80	1.00	0.7	0.80	0.90	1.10	0.70	0.80
	Russelsheim	0.90	1.00	0.75	0.80	0.80	1.00	0.70	0.80
Period 2	Detroit	0.85	1.00	0.75	0.85	0.95	1.10	0.75	0.85
	Russelsheim	1.00	0.80	0.80	0.85	0.85	1.00	0.75	0.85
Period 3	Detroit	0.90	1.05	0.80	0.90	1.00	1.15	0.80	0.90
	Russelsheim	1.00	1.05	0.85	0.90	0.90	1.05	0.80	0.90
Period 4	Detroit	0.90	1.10	0.85	0.95	1.05	1.20	0.85	0.95
	Russelsheim	1.05	1.10	0.90	0.95	0.95	1.10	0.85	0.95

The diagnosed defective rate for various types of materials, provided by different suppliers at different sites and in different periods, are given in table 9.

Table 9 Percent of defectives.

	suppliers	*Cleveland*		*Tokyo*		Shanghai		Madrid	
periods		*product 1*	*Product 2*	*Product 1*	*Product 2*	*Product* 1	*Product* 2	*Product* 1	*Product* 2

Period 1	Detroit	0.0004	0.0005	0.0001	0.0002	0.0008	0.0008	0.0002	0.0003
	Russelsheim	0.0002	0.0003	0.0001	0.0002	0.0006	0.0006	0.0003	0.0004
Period 2	Detroit	0.0005	0.0006	0.0002	0.0003	0.0009	0.0007	0.0003	0.0004
	Russelsheim	0.0003	0.0003	0.0002	0.0003	0.0007	0.0006	0.0004	0.0005
Period 3	Detroit	0.0006	0.0007	0.0002	0.0003	0.0009	0.0007	0.0003	0.0004
	Russelsheim	0.0004	0.0004	0.0002	0.0003	0.0007	0.0006	0.0004	0.0005
Period 4	Detroit	0.0005	0.0006	0.0001	0.0002	0.0008	0.0006	0.0002	0.0003
	Russelsheim	0.0003	0.0003	0.0001	0.0002	0.0006	0.0006	0.0003	0.0004

The values of TQC and TE have been considered 4500000 and 3000, respectively.
Found solutions using weighted sum approach for $w_1 = 0.6, w_2 = 0.2, w_3 = 0.2$ are as follows:
$Z_1 = 2.504452 * 10^8$
$Z_2 = 4.5 * 10^6$
$Z_3 = 1185$
$Z_o = 1.511674 * 10^8$
Also, the total requested quantities are given in table 10.

Table 10 Order quantity from each supplier with $\mathbf{w_1 = 0.60}$, $\mathbf{w_2 = 0.20}$, $\mathbf{w_3 = 0.20}$

$Q_{11} = 300000$	$Q_{31} = 640000$
$Q_{12} = 850500$	$Q_{32} = 860481$
$Q_{21} = 867500$	$Q_{41} = 0$
$Q_{22} = 1523725$	$Q_{42} = 0$

Also, found solutions for $w_1 = 0.7, w_2 = 0.15, w_3 = 0.15$ are as follows:
$Z_1 = 2.504500 * 10^8$
$Z_2 = 4.5 * 10^6$
$Z_3 = 1185$
$Z_o = 1.759868 * 10^8$
And, the total requested quantities are shown in table 11.

Table 11 Order quantity from each supplier with $\mathbf{w_1 = 0.70}$, $\mathbf{w_2 = 0.15}$, $\mathbf{w_3 = 0.15}$

$Q_{11} = 300000$	$Q_{31} = 640000$
$Q_{12} = 146293$	$Q_{32} = 860481$
$Q_{21} = 867500$	$Q_{41} = 0$
$Q_{22} = 1523725$	$Q_{42} = 0$

5. Conclusion

In this research a multi-objective model for supplier selection was offered, in which the cost and quality were considered simultaneously. The results obtained are as follows: By increasing the quality of materials, the purchasing price increases. And by decreasing the quality of materials, the purchasing price decreases. Due to the nature of supplier selection problem, which is an uncertain problem, the suggestions for future research are as follows: One can investigate the proposed model in terms of uncertainty. Among the uncertain methods we can note numerous approaches such as fuzzy set theory and probability theory. Also, one can use combinatorial uncertainty approaches such as Stochastic-Fuzzy Approaches to investigate the proposed model.

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