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Supplier Selection in a Scenario Based Stochastic Model with Uncertain Defectiveness and Delivery Lateness Rates

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Abstract**—**Due to today's globalization as well as outsourcing practices of the companies, the Supply Chain (SC) performances have become more dependent on the efficient movement of material among places that are geographically dispersed, where there is more chance for disruptions. One such disruption is the quality and delivery uncertainties of outsourcing. These uncertainties could lead the products to be unsafe and, as is the case in a number of recent examples, companies may have to end up in recalling their products. As a result of these problems, there is a need to develop a methodology for selecting suppliers globally in view of risks associated with low quality and late delivery. Accordingly, we developed a two-stage stochastic model that captures the risks associated with uncertainty in quality and delivery as well as a solution procedure for the model. The stochastic model developed simultaneously optimizes supplier selection and purchase quantities under price discounts over a time horizon. In particular, our target is the study of global organizations with multiple sites and multiple overseas suppliers, where the pricing is offered in suppliers' local currencies. Our proposed methodology is applied to a case study for a US automotive company having two assembly plants and four potential global suppliers to illustrate how the proposed model works in practice.

Keywords**—**Global supply chains, quality, stochastic programming, supplier selection.

I. INTRODUCTION

DYNAMIC markets lead organizations to be under the pressure of the global competition. An organization's primary goal is satisfy customer demand in high quality and low cost on timely basis. Therefore, the organization should assist, improve and control every element in the Supply Chain (SC) network. The first element in the SC network is supplier since purchasing has an high impact on quality, customer satisfaction, profitability, and market share [2],[16] both in the short or long terms. The purchasing issues, their strategies and plans are important along with marketing, finance, and accounting and operational issues. Purchasing transactions can constitute 55% of an organization's revenue [2].

The global purchasing has been increasing due to the current trends in industrial expansion and globalization. Thus, selecting a supplier becomes a strategic level decision [11]. Currently, the companies are having several sites located worldwide as well as multiple overseas suppliers. Global purchasing has unplanned consequences which enforce organizations to consider sourcing risks and face new challenges that must be considered in the supplier selection process [7]. Some researchers discussed the significant risks associated with global outsourcing; such as [13], [10] and [15]. In particular, the vertical integration between cross-countries and across-times are central to quality issues because of increasing the complexity of network and decreasing the visibility of information. For example, Toyota recalled millions cars because of suppliers' low quality parts [17]. Therefore, supplier selection is a complex decision, which should include both quantitative and qualitative aspects, as well as global factors to account effectively for suppliers' performance.

Supplier selection strategies play a key role in achieving the objective of an effective SC and it should suit the technical requirements as well as the organization's overall strategy. In addition, geographically dispersed suppliers increased the impact of transportation costs and the exchange currency [7]. Thus, the purchasing cost should include whole purchasing process cost in addition to the purchasing price.

In this article, we developed a mix integer optimization model to find a minimal set of suppliers to achieve certain quality and delivery goals while minimizing the risk of having uncertainty in suppliers' quality and delivery. Our techniques are applied for a US automotive firm, considering a typical case reported by [7] and [18] where a global company is purchasing a given product from its different sites. The potential suppliers are evaluated under quantitative data and uncertainty in suppliers' quality and delivery.

The rest of paper is organized as follows. Section II reviews related work. Section III gives the problem formulation of stochastic programing. Section IV presents a case study by applying our approach to the supplier selection problem as a real world case study. The results of the case study and sensitivity analysis are discussed in Section 0. Finally, Section V summarizes this paper and states our future work.

II. RELATED WORK

Many analytical techniques have been used to address the supplier selection problem. The selection of techniques is based on the criteria involved in the process. The supplier selection technique includes all suppliers with critical criteria, which is an important for SC and production and operation management [1], [6], [14] based on organization specific requirements and objectives. Thus, the decision makers try to

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find the best alternative among a set of feasible candidates [1]. Multiple Criteria Decision Makers (MCDC) have been studied in various papers [1], [6], [14]. The decision makers are screening, prioritizing, ranking, and selecting a set of alternatives. In the light of this, finding a supplier who meets most of critical selection criteria is a difficult decision [14].

The purpose of the supplier selection process is to determine the appropriate number of suppliers and finding the optimal replenishing policy for the purchasing quantity [11]. Several deterministic techniques have been developed to meet these objectives besides other considerations, such as quantity discounts [3], lot sizes [4], and inventory levels [5]. However, the deterministic models are not able to handle the randomness inherent in real systems. Researchers have been developing models in supplier selection process without adequately addressing to uncertainty [5]. There are researchers who used the "all-or-none" assumption, such as [12]. On the other hand, in the real world industries are adversity affected by uncertainties both on customer and supplier sides. As a result, stochastic techniques are starting to be implementing in supplier selection research. For instance, [7] applied two-stage stochastic programming for supplier selection while globally considering the currency fluctuations and price discounts. Kara [9] used Fuzzy TOPSIS and a two-stage stochastic model capturing the demand uncertainty. Li and Zabinsky [11] incorporated the uncertainty of demand and supplier capacity for selecting a supplier.

As can be seen from this brief literature review, several multi-criteria supplier selection models were used to minimize the number of suppliers and achieve the organization's objectives. However, none of them capture the quality and the delivery uncertainties. Our study attempts to fill this gap in supplier selection and considers the quality and delivery uncertainties.

III. Methodology

The objective is to minimize the total expected cost purchasing cost with acceptance quality over the planning horizon while satisfying the different problem constraints. The total cost is the sum of supplier selection fixed cost, purchasing cost in suppliers' local currency, transportation cost, inventory cost, and penalty of defectiveness and lateness costs. It is important to consider the exchange currency while selecting a supplier in the global context. The supplier selection fixed cost is encountered when the supplier is selected and refers to having business with the supplier. Each supplier offers its own discount on the purchasing quantity of sales amount with an applicable discount rate. Since the suppliers are allowed to be both local and overseas, there exist different transportation costs associated with the suppliers. Finally, the inventory cost is calculated at buyer's site, depend on its own inventory policies.

A. Problem Formulation

We formulate our mix integer Stochastic Programming (SP) model for the supplier selection problem. The decision makers incorporate SP when they have historical data which can be used as a possible scenario while they do not have the distribution of random variables such as, the demand, delivery, and supplier capacities. Our SP mathematical model captures the risk associated with uncertain defectiveness and delivery lateness rates during a year with fluctuations in the exchange rate from the currency of supplier to standard currency and creates strategic purchasing plan.

There are different scenarios for future defectiveness rates from supplier. Therefore, we use the penalty cost to indicate potential losses in quality and delayed deliveries. The model sets, parameters, and decision variables used in the SP model are defined in Tables I, II, III, respectively.

TABLE I
Model Sets

Sets	Description
i	Set of suppliers
u	Set of plants
n	Set of discounts
t	Time period
s	Set of scenario

TABLE II
Decision Variables in the SP Model

Decision variables	Description
Y_{iu}	Binary integer variable, has value 1 if the supplier i has selected for plant u
x_{iu}^{ts}	Amount of item purchased from supplier i for plant u in time period t and scenario s
Inv_u^{ts}	Inventory level at plant u in period t in scenario s
dis_i^n	Binary integer variable, has value 1 if the purchasing from supplier i falls on the discount interval

TABLE III
Parameter in the SP Model

Parameters	Description
fc_i	Fixed cost of sign contract with supplier i
IC_u	Unit inventory cost at plant u in period t
TC_{iu}	Unit transportation cost from supplier i to plant u
P_i^t	Price of item from supplier i in time period t in the currency of supplier
cap_i	Maximum capacity of supplier i
α_i^t	Exchange rate of the currency of supplier i to standard currency in period t
D_u^t	Demand of item at plant u in time period t
q_i^s	Defectiveness rate of item from supplier i in scenario s
dt_i^s	Delivery lateness rate of item from supplier i in scenario s
θ_q	Quality tolerance in scenario s, equal to 0.05 $\sum_{s,u,t} D_u^{ts}$
θ_d	Delivery tolerance in scenario s, equal to 0.05 $\sum_{s,u,t} D_u^{ts}$
k_q	Penalty cost for defective raw material
k_d	Penalty cost for delivery lateness
DIS_i^n	Minimum limit of purchasing cost in discount price n and in supplier i
DIS_i^{n+1}	Maximum limit of purchasing cost in discount price n and in supplier i
r_{in}	Discount rate n from supplier i
Pro_s	Probability of scenario s

A mutli-objective two-stage stochastic programing model with recourse follows:

$$Min \sum_{s=1}^{S} \Pr o_s \left[\begin{array}{l} \sum_{i=1}^{I}\sum_{u=1}^{U}\sum_{t=1}^{T}\left(1-r_{in}\right)P_i^t x_{iu}^{ts} a_i^t + \sum_{i=1}^{I}\sum_{u=1}^{U}\sum_{t=1}^{T} TC_{iu} x_{iu}^{ts} \\ + \sum_{u=1}^{U}\sum_{t=1}^{T} IC_u x_{iu}^{ts} + \sum_{i=1}^{I}\sum_{u=1}^{U}\sum_{t=1}^{t} k_q q_i^s x_{iu}^{ts} + \sum_{i=1}^{I}\sum_{u=1}^{U}\sum_{t=1}^{T} k_d dt_i^s x_{iu}^{ts} \end{array} \right] + \sum_{i=1}^{I}\sum_{u=1}^{U} Y_{iu} fc_i \quad (1)$$

Our Stochastic program model with two-stage minimizes the total expected cost Z in standard currency with discount. The multiple objective function includes: (1) minimizing the purchasing price (P_{iu}^t) of items multiply by the currency exchange rate (α_i^{ts}); (2) minimizing the total transportation costs (TC_{iu}^t) and the total inventory cost (IC_u^t), respectively; (3) maximizing the quality of receiving items by minimizing the expected cost for defective item (k_q); (4) minimizing the late delivery (k_d) present in the fourth and fifth terms respectively; (5) the fixed cost (fc_i) of selecting supplier.

System constraints:

$$\sum_{i=1}^{I} q_i^s \sum_{t=1}^{T}\sum_{u=1}^{U} x_{iu}^{ts} \le \theta_q \forall s \in S \quad (2)$$

$$\sum_{i=1}^{I} dt_i^s \sum_{t=1}^{T}\sum_{u=1}^{U} x_{iu}^{ts} \le \theta_d \forall s \in S \quad (3)$$

$$\sum_{n=1}^{N} dis_i^n = 1 \forall i \in I \quad (4)$$

$$\sum_{n=1}^{N} dis_i^n DIS_i^n \le x_{iu}^{ts} \le \sum_{n=1}^{N} dis_i^n DIS_i^{n+1} \forall i \in I, 1 \le n \le N \quad (5)$$

$$Inv_u^{1s} = 0 \forall u \in U, s \in S \quad (6)$$

$$Inv_u^{ts} + \sum_{i=1}^{I} x_{iu}^{ts} = Inv_u^{(t+1)s} + D_u^t \forall u \in U, 1 < t \le T-1, s \in S \quad (7)$$

$$\sum_{u=1}^{U} x_{iu}^{ts} \le cap_i Y_{iu} \forall i \in I, 1 \le t \le T, s \in S \quad (8)$$

$$\sum_{i=1}^{I} Y_{iu} \ge 1 \forall u \in U \quad (9)$$

$$x_{iu}^{ts}, I_u^{ts} \ge 0, Y_{iu}, dis_i^n \in \{0,1\} \quad (10)$$

The constraints (2) and (3) determine the requirements for the high quality level and on-time delivery of purchasing items. In particular, the number of defective ($\sum_{i=1}^{I}\sum_{t=1}^{T} q_i \sum_{u=1}^{U} x_{iu}^{ts}$) and lateness ($\sum_{i=1}^{I}\sum_{t=1}^{T} t_i \sum_{u=1}^{U} x_{iu}^{ts}$) items have to be less than the maximum quality and delivery lateness tolerances. In our model, we assume the q_{iu} and t_{iu} equal to $0.05 \sum_{s,u,t} D_u^{ts}$.

Since the main objective is minimizing the purchasing cost, we seek to get discount every time ($dis_i^n = 1$). This is defined by constraint (4). Therefore, the amount of items (x_{iu}^{ts}) should fall in discount range (n) as given in constraint (5).

We assume the inventory level at the first period ($Inv_u^{1\,s}$) is zero as giving in constraint (6). Constraint (7) represents the demand satisfaction. In particular, the sum of inventory at the beginning of time period t (Inv_u^{ts}) and the amount of items purchasing at the same time period ($\sum_{i=1}^{I} x_{iu}^{ts}$) is equal to the sum of the inventory at the beginning of time period $t+1$ ($Inv_u^{(t+1)s}$) and the demand for the same period(D_u^{ts}) under scenario s.

If the supplier i is selected for the period t then amount of items should be less than the supplier capacity as given in constraint (8). According to constraint (9) every plant is served by one supplier at least. Finally constraint (10) specifies the binary and nonnegative properties of decision variables.

IV. Application to a Case Study

Our proposed methodology is applied to the case study presented in [18] for US automotive manufacturing. This company has two assembly plants, the first plant in Detroit, Michigan and the second plant in Russelsheim Germany, with a single part. The annual demand for Detroit is 1,084,500 units and for Russelsheim is 723,000 units. In particular, the demand distributes evenly over the t periods, where each period, t, is assumed to be 3 months (quarter). American dollars (USD) is taken as the currency of reference.

Table IV presents the suppliers' data, including the supplier selection cost(fc_i), the purchasing cost per item in supplier's currency and USD, and the maximum supplier capacity. The suppliers are named after their cities because there is only one supplier in each city. The transportation costs are given in Table V. In particular, the items are shipped from supplier i to plant u either by truck, rail or ship. For instance, the items are shipped from Jakarta, Indonesia through the Suez Canal and enters Europe via Rotterdam and then to Russelsheim via truck. The holding cost per three months period is \$2.56 and \$2.78 in Detroit and Russelsheim, respectively, as assumed by [7].

TABLE IV
SUPPLIER DATA

Supplier	Item base price	Item base price in USD	Supplier selection cost (USD)	Quarterly capacity
Cleveland	22 USD	22	37,500	247,600
Tokyo	2158.17 Yen	21	37,500	247,600
Sao Paulo	47.32 BRL	20	62,500	247,600
Madrid	34.25 EUR	25	37,500	247,600

Since we seek for discounts in every purchasing, the suppliers have discount rates(r_{in}) based on the quantity order during the period t, see Table VII, [7]. These discount rates are used to calculate the item purchasing cost by multiplying the item price and the cumulative for discount rate (($1 - r_{in}$) P_i^t) . For example, the unite price from Tokyo becomes \$

20.79 if the quantity more than 300,000 items and less than 500,000 items. Finally, Table VI presents the quarterly exchange of supplier currency to USD.

TABLE V
TRANSPORTATION COSTS (USD)

Supplier	Detroit	Russelsheim
Cleveland	0.180	3.344
Tokyo	4.400	7.388
Shanghai	4.930	6.974
Madrid	3.316	1.312

TABLE VI
EXCHANGE RATE BASELINE [8]

	Quarter 1	Quarter 2	Quarter 3	Quarter 4
USD/USD	1	1	1	1
USD/Yen	102.770	102.144	103.860	114.045
USD/CNY	6.118	6.158	6.157	6.137
USD/EUR	1.370	1.371	1.325	1.250

The currency exchange rates are obtained from the International Monetary Fund for the year 2014 [8]. The exchange rates are considered to be fluctuations of the suppliers' currencies over the USD on a quarterly basis over one year.

TABLE VII
DISCOUNT SCHEDULE FOR THE DIFFERENT SUPPLIERS [7]

n	DIS_i^n	DIS_i^{n+1}	Discount % (r_{in})
1	0	300,000	0
2	300,000	500,000	1
3	500,000	More than 500,000	3

TABLE VIII
DEFECTIVENESS RATES

Supplier	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Cleveland	0.0489	0.0543	0.0076	0.0548
Tokyo	0.0059	0.0167	0.0328	0.0575
Shanghai	0.0095	0.0582	0.0574	0.0291
Madrid	0.0085	0.0253	0.0549	0.0475

In real life, the defectiveness rates and lateness delivery rates also fluctuate over the time. Here, we let the defective and lateness rates fluctuate over the time; from 0% to 10% for defectiveness and from 0% to 10% for the delays.

A. Impact of Quality Fluctuations

In real-world situations, the defectiveness rate per lot size is not constant as assumed in the previous experiment. We generate different forecasts of defectiveness rates over planning horizon using the methods. At the beginning, we specify a rate of fluctuation; in this case 10%. Then we randomly generate defectiveness rates while ensuring that the defectiveness rates have the flowing lower and upper limits: $0.041 \times (1 - 10\%)$ and $0.041 \times (1 + 10\%)$, where the 0.041 is average value defectiveness rate over the planning horizon for the baseline data given in Table VIII. We solved our model for three cases, which are: the baseline case, +10%, and -10%. As shown in the figures below, the purchasing decisions are different from one model to another.

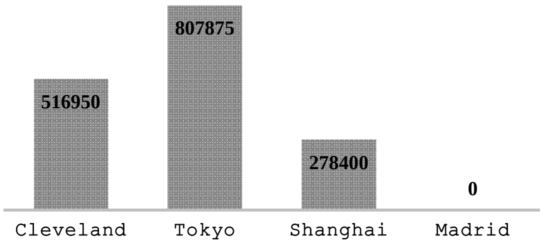

Fig. 1 The purchasing quantity for baseline quality model

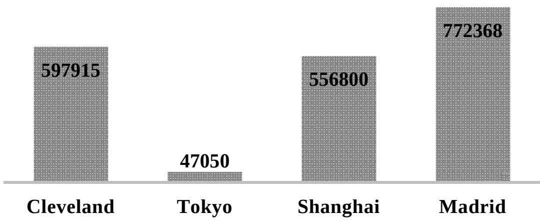

Fig. 2 The purchasing quantity for baseline quality model plus 10%

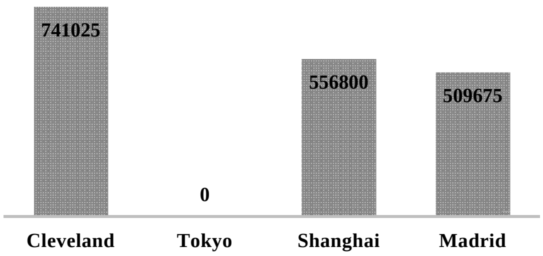

Fig. 3 The purchasing quantity for baseline quality model minus 10%

Regarding the figures above, the quantity purchased is different from one case to another. In other words, the supplier selection and quantity are sensitive for defectiveness rates. In particular, the organization might select supplier with a high change rate but low quality risk in order to reduce the recalling possibility.

B. Impact of Delivery Fluctuating

In the global context, transportation has a huge influence in terms of either freight costs or delivery times. Many works in the literature studied the impact of transportation costs on supplier selection without paying adequate attention to the impact of transportation on timely deliveries as well as on purchasing quantities.

We generate different forecasts of defectiveness rates over the planning horizon using the methods we developed. At the beginning, we specify a rate of fluctuation; in this case 20%. Then we randomly generate defectiveness rates while ensuring that the defectiveness rates have the following lower and upper limits: $0.043 \times (1 - 10\%)$ and $0.043 \times (1 + 10\%)$, where the 0.041 is average value defectiveness rate over the planning horizon for the baseline data given in Table IX. As shown in the figures below, the purchasing decisions are different from one model to another.

TABLE IX
LATENESS RATES

Supplier	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Cleveland	0.04	0.03	0.04	0.06
Tokyo	0.01	0.03	0.01	0.05
Shanghai	0.05	0.02	0.04	0.01
Madrid	0.05	0.0509	0.03	0.02

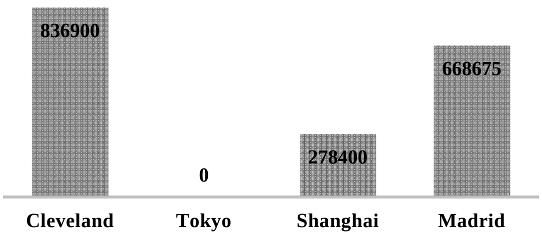

Fig. 4 The purchasing quantity for baseline lateness model

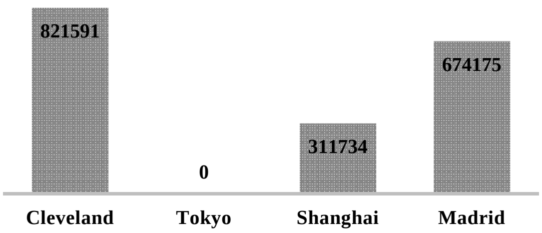

Fig. 5 The purchasing quantity for baseline lateness model plus 10%

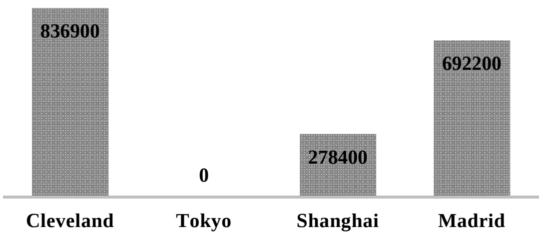

Fig. 6 The purchasing quantity for baseline lateness model minus 10%

Based on Figs. 4-6, we can conclude that the supplier selection and purchased quantity are sensitive to the lateness rate.

V. CONCLUSION

The objective of this study is to analyze the potential of suppliers, and to choose the best candidate using a stochastic programming model. Our problem is a multi-sourcing problem under an uncertain environment. The results guide companies to choose the best suppliers among the candidates. The defectiveness rate should be considered in supplier selection in order to reduce the recalling possibility and loss of customers. In the supplier selection, purchase quantities are found to be more sensitive for quality fluctuations than lateness fluctuations. For instance, the purchasing quantity from Cleveland increases by 80965 items when the defectiveness rate is increased, while it decreased by 15309 items when the lateness rate increases. Also, the purchasing quantity from Married increases by 5096975 items when the defectiveness rate is decreased but in lateness rate it increases by 23525 items.

This model can be extended in different aspects in order to deal with complex decisional issues more accurately. For further research, we will consider more than one item and news suppliers.

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