SOURCING PROBLEM FOR CONSTRUCTION INDUSTRY

Azadeh Mobtaker*, Anjali Awasthi**, Satyaveer Chauhan*** and Sophie D'Amours****

* CIISE, Concordia University, Montreal, Quebec, H3G1M8, Canada,
Email: mobtaker6@yahoo.com
** CIISE, Concordia University, Montreal, Quebec, H3G1M8, Canada,
Email: awasthi@ciise.concordia.ca
*** DSMIS, Concordia University, Montreal, Quebec, H3G1M8, Canada,
Email: satyaveer.chauhan@concordia.ca
**** Universite Laval, Quebec, Quebec, Canada, Email: sophie.damours@forac.ulaval.ca

Abstract In construction projects, availability of required material at right time at the project site is crucial to complete the project on time and within the budget. The construction project could be delayed for several reasons and this may disrupt supplies. In this work we assume that enough supply may not be available on time if the project delayed excessively unless the project manager has special supply contracts with the suppliers. Usually suppliers react in two ways towards change in delivery dates; either they may increase the price or provide a limited quantity on the negotiated price. In this work we discuss both the cases and provide solution approaches. The efficiency of the approaches is verified using randomly generated data sets.

Paper type: Research Paper

Published online: 30 July 2013
Vol. 3, No. 3, pp. 167-182

ISSN 2083-4942 (Print)
ISSN 2083-4950 (Online)

Keywords: *supply chain, supplier selection, construction, heuristic*

1. INTRODUCTION

Managing material supply in construction industry is very different from manufacturing. In general construction is done in several phases and project competition time is generally much longer than manufacturing. Even the exact demand is known, there are several exogenous events, such as delays in permit, inspection, material quality, availability of material, labor, weather, etc., that can affect the project completion date. Since, each construction phase has specific requirements; delay in any of the phase affects the planning of subsequent phases. Resource availability and work availability are two common limitations that constrain the construction progress. Work availability limitations are usually expressed by internal or external dependencies in a construction project. Since these dependencies are related to the nature of work, normally the project manager is not able to control them. In contrast, resource availability limitations can be controlled by the project manager by means of resource plans and managerial decisions. It seems that construction management is nothing but resource management which leads to a huge number of resource management and procurement studies (Park 2004).

In some industries raw material and supplies are required for a short duration, in which long term commitment with suppliers doesn't seem a wise decision. Moreover suppliers usually aren't interested in increasing their production capacity because of either absence of long term relationships or technical constraints. For example in Canadian Wood-Frame House Construction projects, wooden material is supplied from forestry industry, in which suppliers cannot augment their capacity due to technical constraints. Forests are owned by several suppliers with limited number of trees. A desirable requirement (with particular quantity, quality, etc.) may not be met by one supplier due to either limited capacity or reserved capacity for other clients. Consequently, it is inevitable for the buyer companies (e.g. saw-mills/furniture companies) to buy from multiple suppliers in order to maintain competition and avoid various risks such as price, quality and delivery uncertainties (Awasthi, Chauhan, Goyal & Proth 2009). Additionally studies have recommended that "single sourcing is a dominant strategy only when supplier capacities are large relative to the product demand and when the firm does not obtain diversification benefits. In other cases multiple sourcing is an optimal sourcing strategy" (Burke, Carrillo & Vakharia 2007).

In engineering, procurement and construction (EPC) industries supply cost is a big portion of total expenses of a company. So having enough supply at the right time is critical and crucial to complete a construction project on time and within budget; then appropriate supply management and specifically supplier selection and quantity allocation methodologies are effective to improve the project performance indicators like cost and time and supply chain efficiency in general.

Supplier selection involves several criterias which may be qualitative or/and quantitative in nature. In a typical selection process the suppliers are first short-listed based on qualitative criteria and then finally selected based on quantitative criteria. Qualitative criteria includes parameters such as service quality level, reliability, flexibility, customer relationship, etc. Most of the researchers proposed tools such as Analytic Hierarchy Process (AHP), TOPSIS, fuzzy logic, etc for evaluating suppliers on qualitative parameters. Readers interested in qualitative tools applicable to supplier selection problem may refer (Wu, Blackhurst & Chidambaram 2006), (Kahraman, Cebeci & Ulukan 2003), Lee (2010), (Punniyamoorthy, Mathiyalagan, & Parthiban 2011), and (Bhattacharya, Geraghty, & Young 2010). Quantitative approaches are most commonly used when numerical data is available. Most of these studies in the area of supplier selection emphasizes on optimal quantity allocation. In this review, we will divide approaches under two categories: suppliers with limited capacity or unlimited capacity. In the first case, we assume that the supplier has limited capacity while in the second case enough capacity to fulfill the cleint's demand. Demand could be deterministic or stochastic. In the deterministic case both demand quantity and demand delivery time from buyer side are known and fixed. In the stochastic situation, demand quantity and/or delivery time are subject to change by the buyer and may vary over time.

In the area of deterministic demand conditions, Chauhan and Proth (2003) explored supplier selection problem with fixed demand for two different situations: a manufacturing unit with several providers and multi-providers for multi-manufacturing units. In that study each supplier quotes a fixed setup cost plus a concave increasing cost of the quantity delivered. The authors proposed a heuristic algorithm based on properties of an optimal solution to allocate appropriate quantities to the suppliers which should be within a maximum and minimum range. (Burke, Carrillo & Vakharia 2008) studied same problem as (Chauhan & Proth 2003) but instead of considering a fixed setup cost plus concave quantity discount for suppliers, (Burke, Carrillo & Vakharia 2008) studied three different pricing schemes including linear discounts, incremental units discounts and all units discounts. The authors proposed a heuristic model to solve the problem. (Chauhan et al. 2005) proposed an optimal algorithm based on dynamic programming for supplier selection problem (SSP) for single buyer. (Burke, Carrillo & Vakharia 2008) studied a problem motivated by a purchasing organization that source from a set of suppliers. In which each supplier offers an incremental quantity discount purchase price structure. The objective is to obtain required supply at minimum cost. Authors solved this allocating order quantities problem by minimizing the sum of separable piecewise linear concave cost functions. A branch and bound algorithm has been developed to reach the optimal solution. Glock (2010) studied an integrated inventory system for a supply network, in order to minimize total system cost. Glock (2010) assumed deterministic conditions for all the parameters over time and proposed a heuristic model.

A single item, multi-supplier system with fixed demand, price-quantity discount considerations, suppliers' capacities constraints has been explored by (Chang 2006), and the author used a mixed integer approach to solve the procurement problem. (Sawik 2010) explored supplier selection problem for a custom company in a make to order environment. Sawik considered three factors in selection process such as: price, quality of custom parts and reliability of on time delivery. Business volume discount is also considered and a mixed integer program was proposed to solve the problem. (Rezaei & Davoodi 2010) studied a multi-product, multi-supplier and multi-objective (cost, quality and service level) supplier selection problem and proposed two multi-objective mixed integer nonlinear models. (Mendoza & Ventura 2010) investigated a system of supplier selection and inventory management to optimize the entire system. A mixed integer nonlinear programming model is used that gives an optimal inventory policy while allocating appropriate quantity to chosen suppliers. The authors assumed a single-product case and constant demand rate. (Kokangul & Susuz 2010) utilized hierarchy process and non-linear integer and multi-objective programming with consideration supplier capacity, total budget and quantity discount constraints; while the objective functions were maximizing the total value of purchase (TVP), minimizing the total cost of purchase (TCP) or maximizing TVP and minimizing TCP simultaneously.

Combination of analytic hierarchy process (AHP) and goal programming (GP) has been utilized in a study by (Kull & Talluri 2007) as a tool for strategic supplier selection in the presence of risk measures and product life cycle considerations. Also (Jolai, Yazdian, Shahanaghi & Khojasteh 2010) studied supplier selection and order allocation problem in a fuzzy environment. First suppliers are evaluated by use of fuzzy MCDM, fuzzy AHP and modified fuzzy TOPSIS; then with help of goal programming method the problem has been modeled in a mixed integer linear program. (Woo & Saghiri 2010) defined a supplier selection problem as a multiple-objective decision making problem under uncertainty and proposed a fuzzy multiple-objective mixed-integer programming model to assign quantity to each supplier. The authors assumed three main stage of the supply chain: the purchasing organization, suppliers, and third-party logistics providers. This was a multiple-product problem in which suppliers had limited capacity. (Ebrahim, Razmi & Haleh 2010) approached vendor selection problem as a multi-criteria decision making problem with consideration of different discount schemes (such as all unit-cost, incremental discount, and total business volume discount) on the unit price at the same time. Suppliers' capacity and demand constraints are also considered. As a result of their study, a scatter search algorithm is proposed while using the branch and bound method.

Yeh and Chuang (2010) studied supplier selection problem in a multi-product, multi-stage supply chain. In their study a multi-objective genetic algorithm is used to reach a balance among four conflicting objectives such as cost, time, product quality and green criteria; capacity constraint and constant market demand had been assumed. (Micheli, Cagno & Giulio 2009) found out that combination of total cost of ownership (TCO) approach and supplier-specific guidelines for immediate and later interventions will lead to some "present total cost profiles" (PTCP) which include the variability and the single value of total cost for each intervention for every supplier that can be used for decision makers to subjectively utilize their related experiences to make the best decision.

(Wan & Beil 2009) studied how to choose a qualified supplier to win a contract by use of a combination of request-for-quotes (RFQ) reverse auction and supplier qualification screening. The authors explored how well determining the level of qualification prior and after auction can decrease total expected procurement cost. The authors utilized mathematical programming techniques methods to compute the expected prequalification, auction and post qualification costs and by the use of mathematical methods, the optimal auction is achieved.

There are a few researches with unrestricted supply conditions. For instance, (Keskin, Uster, & Ctinkaya 2010) studied a supplier selection and quantity allocation problem with fixed demand for a multi-store firm and single-product; the authors proposed an integrated vendor selection and inventory optimization model by use of a mixed integer nonlinear programming.

Stochastic demand conditions

In opposite of deterministic demand conditions in supplier selection process, procurement problems can be explored when demand conditions such as demand quantity and/or demand delivery time are subject to change. These circumstances are closer to real-world conditions then approaches towards them usually lead to more robust supply chain partnerships.

(Abginehchi & Zanjirani Farahani 2010) investigated multiple-supplier, single-item inventory systems with random lead-times and both constant and probabilistic demand. By the use of a mathematical model the researchers determined the reorder level and quantity allocation for each supplier to minimize cost including ordering, procurement, inventory holding and shortage cost.

For a single-item, multi-supplier system, (Chang, Chin & Lin 2006) considered fixed demand and variable lead-time, price-quantity discount (PQD) and resource constraints. To solve this problem a mixed integer approach was used to minimize cost. The cost function includes total periodic purchasing with PQD, ordering, holding, and lead-time crashing cost.

In modern supply chains, lots of uncertainties and variations are related to demand quantity and supply lead-times which high lights the importance of flexibility in vendor selection process. Flexibility can be defined as robustness of buyer-supplier relationship under changing supply conditions. Das and Abdel-Malek (2003) formulated a measure for flexibility as a function of varying order quantities and varying supply lead-times.

Some of common criteria in supplier selection are cost, quality, delivery and flexibility. (Liao & Rittscher 2007) made a summation of four functions for cost including expected purchasing cost, demand quantity increase penalty, demand quantity decrease penalty and demand timing decrease penalty; also for flexibility (Liao & Rittscher 2007) used Das and Abdel-Malek (2003) flexibility measurement formulation and finally for quality and delivery, quality rejection rate and late delivery rate were evaluated. Two equality and inequality constraints were associated with demand satisfaction and capacity constraints respectively. Since dealing with equality constraints in multi-objective problems is relatively difficult, a problem specific operator Demand along with genetic algorithm method has been used to solve the problem.

(Zhang & Zhang 2010) explored supplier selection and purchase problem with uncertain demand quantity. The authors assumed minimum and maximum constraint on the order quantity for each supplier. The objective was to minimize the total cost. It was assumed since at the time of signing the contract with suppliers, buyer does not know the certain amount of demand, if the buyer orders more than the realized demand, the excess stock causes a holding cost or on the other hand if order quantity is less than the real demand, a penalty cost is incurred. So several cost types have been considered including selection, purchase, holding and shortage costs. Finally the problem was modeled by a Mixed Integer Program (MIP).

(Jafari, Tavana, Azadeh, & Songhori 2010) investigated the supplier selection and quantity allocation problem in two evaluation and allocation phases: first a data envelopment analysis (DEA) model is used with consideration of several factors like cost, time and quality (ordering and transportation costs are inputs for the DEA model while lead-time mean and variance (lead-time is assumed to be a stochastic variable), and supplier quality score are output variables in the DEA model); second a multi-objective mixed integer programming model had been developed to minimize the total costs and maximize the overall efficiencies. It was assumed each supplier has a limited capacity.

Shi and Zhang (2010) combined multi-product acquisition and pricing problems where there is uncertain demand, budget constraint and supplier quantity discount. A mixed integer non-linear program is used to model this problem.

Awasthi, Chauhan, Goyal, and Proth, (2009) used a similar heuristic method to (Chauhan & Proth 2003) for supplier selection problem while facing stochastic demand with fixed product price. Burke et al. (2007) also studied supplier selection problem with uncertain demand and consideration of suppliers' capacities and cost, product price, firm inventory costs and historical supplier reliabilities. Authors proposed an optimal approach in the case where a set of selected suppliers with limitations on minimum order size, must supply to a buyer facing uncertain demand. The main difference of their work and (Awasthi, Chauhan, Goyal, & Proth, 2009) is that Burke et al. (2007) only assigned quantities to the suppliers who must supply a positive quantity.

Li and Zabinsky (2009) incorporated uncertainties in demand and supplier capacity in the supplier selection process. These uncertainties are captured by scenarios or with a probability distribution in two models: a stochastic programming (SP) model and a chance-constraint programming (CCP) model have been proposed to find minimal set of suppliers and order quantities with consideration of business volume discounts. Quality, delivery and cost (including purchasing, transportation and inventory costs) are the objectives considered in these models. Moreover, in order to analyze the tradeoffs between cost, risk of not meeting the demand and number of suppliers, multi-parametric programming techniques have been utilized.

In this paper we focus on deterministic demand conditions i.e. we know the end demand but a supplier may offer multiple prices. The rest of the paper is divided into three sections. Problem formulation, solution approach and numerical experimentations are presented in section 2, and finally conclusion and future research directions are provided in section 3.

2. THE PROBLEM

2.1. Problem setting and Formulation (1)

In this problem we assume that a project manager is facing an uncertain start date for an activity. A material required for this activity is crucial to start the activity and the price of this material depends upon the source of sourcing and delivery date. We assume that the project manager has complete information about the prices offered by the suppliers as well as probability of the project delay with duration. The demand for the activity is known and constant. Each supplier may impose limits on the minimum and maximum order size for economy of scales and capacity limits respectively. The objective is to select set of supplier to fulfil the demand in the most economical way.

Let S be the set of scenarios for delays (to start the activity) f_s, $s \in S$ be the probability of scenario s. We assume n number of suppliers are available and offering $p_{i,s}$ per unit price, where $i \in \{1,2,...,n\} = N$, in scenario $s \in S$. In this model we assume that each supplier either supplies a quantity which lies between $[m_i, M_i]$ or don't supply anything. The following formulates the problem:

$$P_1 \qquad Min \sum_{i \in N} \sum_{s \in S} p_{i,s}.q_i.f_s$$

s.t.

$$Z_i M_i \geq q_i \geq Z_i.m_i \ \ \forall i \in N \tag{1}$$

$$\sum_{i \in N} q_i \geq d \tag{2}$$

$$Z_i \in \{0,1\}, \ \forall i \in N \tag{3}$$

The objective of P_1 is to minimize the expected purchasing cost. Constraints (1) make sure that supplier either supplies a quantity within the stipulated range or do not supply anything. Constraint (2) is demand satisfaction constraint i.e. all the suppliers combine must satisfy the demand d. Finally, last constraints define Z as binary variable.

Proposition 1: P_1 is NP hard problem.
The proof is very similar to the proof presented in (Chauhan et el 2005)

Proposition 2: For an optimal solution the quantity supplied by each supplier, may be except for one, belongs to $\{m_i, M_i, 0\}$ i.e. $q_i \in \{m_i, M_i, 0\}$.

The proof is presented in (Chauhan and Proth, 2003). It can be concluded from proposition 1 that an exact algorithm for P_1 may not be computationally efficient. This motivates use to develop a heuristic approach for the above problem. In the proposed heuristic we make sure that any local solution generated by the heuristic algorithm must satisfy the conditions outlines by the proposition 2. Because of the nature of the problem, we propose two heuristics.

2.2. Heuristic 1 (S1)

I. Compute the average price offered by each supplier.
II. Arrange the suppliers in the increasing order of their average quoted price.
III. For supplier, i=1 to N

a) If $d \geq M_i$: Assign the amount M_i to supplier i $(x_i = M_i)$, and $set\ d = d - M_i$.
b) If $d \in [m_i, M_i]$: Assign d to supplier i $(x_i = d)$, compute the solution, and go to the end of the program.
c) If $d < m_i$, set i^*=i

T1. Then for each supplier $j \geq i^*$, set $x_j \geq m_j$ and assign rest of the quantity among suppliers $1, 2, ..., j$.
We first assign $x_j = m_j$ *and set* $d^j = d - x_j$. *We then assign* d^j *to suppliers (1,2,..j). The assignment should maintain the conditions outlined in proposition 2.*
T2. If the assignment is successful, compute the cost of current assignment. Keep the assignment if the cost is better than all the previous assignments.

IV. End.

Heuristic 2 (S2)

1. For each scenario $s \in S$
   1.1 Arrange the suppliers in the increasing order of their quoted price (for current scenario).
   1.2 For supplier, i=1 to N
      1.2.1 If $d \geq M_i$: Assign the amount M_i to supplier i $(x_i = M_i)$, and $set\ d = d - M_i$.
      1.2.2 If $d \in [m_i, M_i]$: Assign d to supplier i $(x_i = d)$, compute the solution and go to 2.
      1.2.3 If $d < m_i$, set i^*=i
         1.2.3.1 Then for each supplier $j \geq i^*$, set $x_j \geq m_j$ and assign rest of the quantity among suppliers $1, 2, \ldots, j$.
         We first assign $x_j = m_j$ and set $d^j = d - x_j$. We then assign d^j to suppliers (1,2,..j). The assignment should maintain the conditions outlined in proposition 2.
         1.2.3.2 If the assignment is successful, compute the expected cost for current assignment. Keep the assignment if the cost is better than all the previous assignments.

2. Compute the expected cost for the current assignment. Keep the best assignment across the iterations.

3. End.

2.3. Problem setting and formulation (2)

This problem is set in the same context however in this problem we assume that the suppliers may not offer the same promised quantity if the activity starting date is delayed. This assumption is realistic as suppliers are generally part of several supply chains and they may not be able to keep promised capacity for an extended duration. For simplicity we assume that all suppliers reduce the promised quantity with the delay however the quoted price remains the same. In this situation the buyer may order more than the required quantity assuming in the event of project delay the net received quantity (after the reduction) should be as close as possible to the required demand. But in the event of no-delay the buyer should buy all the reserved quantity i.e. (probably) more than the demand.

This situation is very similar to newsvendor problem but with multiple vendors. Let $\alpha_{i,s}$ $(0 \le \alpha_{i,s} \le 1)$ be the fractional delivery (delivered quantity/ promised quantity) available (w.r.t. promised delivery) by supplier $i, i \in N$, in scenario $s, s \in S$. In other words, if buyer placed an order of q_i (the promised quantity) then, in scenario s the supplier will be able to provide only $\alpha_{i,s}.q_i$ $(< q_i)$ units. If the total available quantity by all suppliers are less than the demand, d, then the missing quantity in that scenario, $q_{m,s}$ must be acquired from open market at price p_m. We assume that this price is higher than the price offered by any of the available supplier. Now the problem at hand can be reformulated as follows:

$$P_2 \qquad Min \sum_{s \in S} f_s . \left(\sum_{i \in N} p_i . q_i . \alpha_{i,s} + p_m q_{m,s} \right)$$

s.t.

$$Z_i M_i \ge q_i \ge Z_i . m_i \quad \forall\, i \in N \tag{4}$$

$$\sum_{i \in N} \alpha_{i,s} q_i - \delta_s + q_{m,s} = d \quad \forall\, s \in S \tag{5}$$

$$Z_i \in \{0,1\} \quad \forall i \in N \tag{6}$$

$$\delta_s \ge 0, \quad \forall\, s \in S \tag{7}$$

$$q_{m,s} \ge 0, \quad \forall\, s \in S \tag{8}$$

The goal is to minimize the expected purchasing cost. Constraints (4) maintain the order size restrictions on the suppliers. Constraints (5) compute the missing quantity (to be purchased at the market price) in each scenario, if any.

2.4. Solution approach

The structure of this problem is very similar to P_1 and therefore this problem is also NP-hard. We propose an approach based on heuristic 1 (S1). In S1, we arrange supplier based on average price however, to solve problem P2, we arrange suppliers in an ascending order based on supplier specific cost-based-score. To obtain this score for a given supplier, we first solve single supplier problem assuming that this supplier is capable of providing any quantity. In other words we assume that the buyer is buying all material from this supplier and, if required, from the open market (no other suppliers are available). To obtain this score (cost) we first assume that there is no limitation on upper order limit. Then we use marginal analysis to compute the order quantity. Once we obtained the order quantity, we compute the expected cost and this expected cost becomes the cost based score of this supplier. We compute this score for every supplier and arrange the suppliers in ascending order of this score.

Once the suppliers are arranged, we follow the step 3 of algorithm S1.

2.5. Numerical Experimentation

In this section we first present numerical examples to illustrate the problem and the solution. Table 1 compiles the detailed solution obtained from S1 and S2. Since S1 works on average cost, it requires less computation than S2. We can see from Table 1 and Table 2 that S1 performs as good as S2 and requires less number of steps.

Table 1 Illustrative Examples (P1)

Number of suppliers	**(m) and (M) limits**	**Demand**	**S1 Quantity allocation**	**S1 Cost**	**S2 Quantity allocation**	**S2 Cost**
3	m=[8 16 6] M=[41 26 11]	63	26 26 11	$745.84	26 26 11	$745.85
4	m=[13 17 22 16] M=[63 24 37 40]	139	63 24 36 16	$1570.9	63 24 36 16	$1570.9
5	m=[10 7 1 12 17] M=[24 33 14 27 50]	132	24 33 14 27 34	$1612	24 33 14 27 34	$1612
6	m=[15 18 10 2 12 2] M=[52 20 58 40 59 28]	77	47 18 0 0 12 0	$855.7	52 0 0 0 25 0	$854.4
6	m=[10 22 11 6 15 12] M=[55 69 52 42 53 57]	245	55 69 52 0 15 54	$2645	55 69 52 0 15 54	$2645
7	m=[67 66 51 77 55 58 82] M=[332 360 245 377 244 238 216]	1065	332 66 245 0 244 178 0	$12118.33	332 66 245 0 244 178 0	$12118
7	m=[1 12 1 12 24 7 10] M=[23 54 43 35 44 54 48]	203	0 33 43 35 44 0 48	$2417.6	0 54 43 0 44 14 48	$ 2419.8
8	m=[61 95 89 95 65 84 84 57] M=[214 215 319 217 340 341 233 232]	394	0 0 0 0 337 0 0 57	$4534.1	0 0 0 0 337 0 0 57	$4534.1
8	m=[15 5 8 12 9 8 12 6] M=[17 38 16 53 30 25 50 44]	175	17 38 16 46 0 8 50 0	$1986.7	17 38 16 29 0 25 50 0	$1987.2
10	m=[7 1 10 11 8 8 7 24 22 10]	250	26 30 0 25 58 0	$2865.7	26 30 0 25 58 0 0 24	$2865.7

	M=[31 30 35 25 58 18 51 26 39 48]		0 24 39 48		39 48	
11	m=[10 17 21 20 10 5 17 1 8 16 15] M=[27 67 28 57 18 27 59 19 12 44 29]	220	27 0 21 57 18 0 59 9 0 0 29	$2453.3	27 0 21 57 18 0 59 9 0 0 29	$2453.3
12	m=[13 20 12 21 9 25 7 2 19 21 24 9] M=[54 47 36 63 57 29 43 14 39 35 66 59]	212	0 0 0 0 0 29 0 14 39 35 36 59	$2466.2	0 0 0 0 0 29 0 14 39 35 66 29	$2468.3
13	m=[20 5 23 18 17 25 1 11 13 15 3 17 2]	333	48 41 23 0 28 58 21 0 0 29 16 40 29	$3848.174	48 41 0 18 28 58 21 0 0 29 16 45 29	$3850.2

In Table 2 we present the performance of the heuristic algorithm by comparing the heuristic solution with the optimal solution. To obtain the optimal solution we examine all the possible assignment of the available suppliers and select the best assignment based on the expected cost. In the table we present the mean relative error and standard deviation of the mean relative error. We solved 100 randomly generated instances for each problem size to compute the mean and standard deviation of the relative error (Heuristic solution – Optimal solution)/ optimal solution.

Table 2 Computational Results (P1)

Number of suppliers	Mean error (s1)	Standard deviation of mean error (s1)	Mean error (s2)	Standard deviation of mean error (s2)
3	0	0	0.00014221	0.001415
4	5.69E-05	0.000566393	0.00020476	0.002037
5	6.25E-05	0.000524476	0.00004967	0.000494
6	7.57E-05	0.000671282	0.00020959	0.001245
7	0.000648	0.000648248	0.00030173	0.001471
8	6.19E-05	0.000429126	0.00037036	0.001483
9	8.36E-05	0.000831419	0.00037962	0.001476
10	1.95E-05	0.000194248	0.00025703	0.00213
11	6.92E-05	0.000336116	0.00034692	0.00188
12	0.000103	0.000798585	0.0005197	0.002244
13	2.51E-05	0.000215389	0.00077686	0.0023
14	4.16E-05	0.000241688	0.00038815	0.001704
15	1.14E-05	7.15512E-05	0.00042455	0.00192

The problem is solved using both the approaches and results are summarized in Table 2. From Table 2, we can observe that the mean error as well as standard deviation of the mean error is small. In other words, the heuristic approach developed in this paper works well for this problem. Note that there were few instances where heuristic was not able to find the feasible solution however, a solution was exist. In the computation of mean relative error we removed such instances.

To test the performance of S3 (heuristic for P2), we generated 20 random problems for each problem size and computed the relative error. To obtain the optimal solution, we again computed the each possible combination of suppliers and obtained the best assignment based on minimum expected cost. Table 3 summarises the results. We can see that error is small and the approach could be used effectively to generate a quick solution which could be enough close to the optimal solution. Note that, a branch-and-bound technique could be used to explore the optimal solution and this heuristic approach can be used to generate a quick upper bound.

Table 3 Computational results (P2)

No. of suppliers	Mean error	Standard deviation of error
3	0.0029	0.013
4	0.000289	0.0011
5	0.0019	0.0063
6	0.010	0.018
7	0.0033	0.009
8	0.005	0.018
9	0.0025	0.0049
10	0.0033	0.005

In Table 3 we can see that although the error is small but it does not provide any pattern w.r.t. problem size. The one possible reason could be the number of instances was not enough. But in our view the problem complexity is not always due to number of suppliers but mostly due to upper and lower order limits set by the suppliers. If this limit is closer to each other, the problem becomes more complex. Since we are generating all these limits randomly, adding one or more supplier in the problem doesn’t mean always a complex problem.

3. CONCLUSION

This work presents two models and approaches to select a set of suppliers to fulfil demand. The problem of selecting suppliers under mentioned constraints with stochastic project completion date is computationally complex problem. The approach presented in this work is easy to implement and provides a solution which is close to the optimal solution. The tool presented here could be very useful in the environment where parameters related to suppliers (such as production rate, capacity, etc) changes frequently and managers have to modify the plan by adding/removing suppliers or modify quantities as the project progresses and demand changes. The approach presented here could be useful in extending the research in the direction of multi-product supply planning. Advanced approaches such as bender decomposition could be investigated in future to develop exact algorithms.

ACKNOWLEDGEMENTS

All authors will greatfully acknowledge the NSERC fundings for this project.

REFERENCES

Abginehchi S., & Zanjirani Farahani R., (2010). "Modeling and analysis for determining optimal suppliers under stochastic lead times". Applied Mathematical Modelling,Vol. 34, pp. 1311–1328.

Agarwal, N., & Nahmias, S., (1997). "Rationalization of the supplier base in the presence of yield uncertainty". Production and Operations Management.

Awasthi A. , Chauhan S.S., Goyal S.K., & Proth J., (2009). "Supplier selection problem for a single manufacturing unit under stochastic demand". International Journal Production Economics, pp. 229–233.

Bhattacharya A., Geraghty J., & Young P., (2010). "Supplier selection paradigm: An integrated hierarchical QFD methodology under multiple-criteria environment". Applied Soft Computing 10, pp.1013–1027.

Burke G. J., Carrillo J., & Vakharia A. J., (2007). "Heuristics for sourcing from multiple suppliers with alternative quantity discounts". European Journal of Operational Research 186, pp. 317–329.

Burke G., Geunes J., Romeijnb H. E., & Vakharia A., (2008). "Allocating procurement to capacitated suppliers with concave quantity discounts". Operations Research Letters vol. 36, pp. 103 – 109.

Chauhan S. S., & Proth J.M., (2003). "The concave cost supply problem". European Journal of Operational Research, pp. 374-383.

Chauhan S. S., Eremeevb A. V., Romanovac A. A., Servakhd V. V., & Woegingere G. J., (2005). "Approximation of the supply scheduling problem". Operations Research Letters 33, pp. 249 – 254.

Chang C., Chin C., & Lin M., (2006). "On the single item multi-supplier system with variable lead-time, price-quantity discount, and resource constraints". Applied Mathematics and Computation 182, pp. 89–97.

Chang C., (2006). "An acquisition policy for a single item multi-supplier system with real-world constraints". Applied Mathematical Modelling 30, pp. 1–9.

Glock C. H., (2010). "A multiple-vendor single-buyer integrated inventory model with a variable number of vendors". Computers and Industrial Engineering.

Jafari Songhori M., Tavana M., Azadeh A., & Khakbaz M. H., (2010). "A supplier selection and order allocation model with multiple transportation alternatives". International Journal Adv. Manuf. Technol.

Jolai F., Yazdian S. A., Shahanaghi K., & Azari Khojasteh M., (2010). "Integrating fuzzy TOPSIS andmulti-period goal programming for purchasing multiple products from multiple suppliers". Journal of Purchasing & Supply Management.

Kahraman C., Cebeci U., & Ulukan Z., (2003). "Multi-criteria supplier selection using fuzzy AHP", Logistics information management, pp. 382-394.

Keskin B. B., Uster H., & Ctinkaya S., (2010). "Integration of strategic and tactical decisions for vendor selection under capacity constraints". Computers & Operations Research 37, pp. 2182–2191

Kokangul A., & Susuz Z., (2009). "Integrated analytical hierarch process and mathematical programming to supplier selection problem with quantity discount". Applied Mathematical Modelling 33, pp. 1417–1429.

Kull T. J., & Talluri S., (2007). "A supply risk reduction model using integrated multi criteria decision making". IEEE Transactions on Engineering Management 55, No.3.

Liao Z., & Rittscher J., (2007). "A multi-objective supplier selection model under stochastic demand conditions". International Journal of Production Economics vol. 105, pp.150-159.

Li L., & Zabinsky Z. B., (2009). "Incorporating uncertainty into a supplier selection problem". International Journal Production Economics.

Lee A. H.I., (2009). "A fuzzy supplier selection model with the consideration of benefits, opportunities, costs and risks". Expert Systems with Applications 36, pp. 2879–2893.

Mendoza A., & José A. Ventura, (2010). "A serial inventory system with supplier selection and order quantity allocation". European Journal of Operational Research vol. 207, pp. 1304–1315.

Micheli G. J.L., Cagno E., & Giulio A. D., (2009). "Reducing the total cost of supply through risk-efficiency-based supplier selection in the EPC industry". Journal of Purchasing and Supply Mangement 15, pp.166-177.

Mohammad Ebrahim R., Razmi J., & Haleh H., (2009). "search algorithm for supplier selection and order lot sizing under multiple price discount environment". Advances in Engineering Software 40, pp. 766–776.

Park M., (2004). "Model-based dynamic resource management for construction projects". Automation in Construction 14, pp. 585-598.

Punniyamoorthy M., Mathiyalagan P., & Parthiban P., (2011). "A strategic model using structural equation modeling and fuzzy logic in supplier selection". Expert Systems with Applications 38, pp. 458–474.

Rezaei J., & Davoodi M., (2010). "Multi-objective models for lot-sizing with supplier selection". International Journal of Production Economics,

Sawik T. , (2010). "Single vs. multiple objective supplier selection in a make to order environment". Omega 38, pp. 203–212.

Shi J., & Zhang G., (2010). "Multi-product budget-constrained acquisition and pricing with uncertain demand and supplier quantity discounts", International Journal Production Economics 128, pp. 322–331.

Wan Z., & Beil D. R., (2009). "RFQ Auctions with Supplier Qualification Screening". Operation Research 57, pp. 934-949.

Woo H.S., & Saghiri S., (2010). "Order assignment considering buyer, third-party logistics provider and suppliers". International Journal of Production Economics.

Wu T., Blackhurst J., & Chidambaram V., (2006). "A model for inbound supply risk analysis". Computers in industry 57, pp. 350-365.

Yeh W. C., & Chuang M.C., "Using multi-objective genetic algorithm for partner selection in green supply chain problems", Expert Systems with Applications, ARTICLE IN PRESS

Zhang J., & Zhang M., (2011). "Supplier selection and purchase problem with fixed cost and constrained order quantities under stochastic demand". International Journal of Production Economics 129, pp.1–7.

BIOGRAPHICAL NOTES

Azadeh Mobatker is a graduate student in the areas of Management Science at the Concordia University Montreal. Her research interests include, Management Science, forest product industries and simulation.

Anjali Awasthi is an Assistant Professor at Concordia Institute of Information and System Engineering, Her research interests includes System analysis, simulation, sustainable transportation, city logistics.

Satyaveer Chauhan is an Associate Professor at John Molson School of Business. His research interest includes applied Operations research, Supply chain and forest product industries.

Sophie D'Amours is currently a vice-provost research at Universite Laval. She is heading a research group on forest product industries and held several research chairs in the past. Her research interest includes Operations Research, Supply chain, forest product industries, manufacturing and system analysis.