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Wood based construction project supplier selection under uncertain starting date

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Abstract:

There is a growing interest in supply management systems in today's competitive business environment. Importance of implementing supply management systems especially in home construction industry is due to the fact that several risks arising from different sources can adversely affect the project financially or its timely completion. Some risks of construction projects are out of managers' control while other risks such as supply related ones can usually be controlled and directed by effective managerial tactics. In this paper, we address the supplier selection problem (SSP) in wood-based construction industry (housing projects) in the presence of project commencement uncertainties. Based on the suppliers(vendors') reaction towards these uncertainties in the delivery time, we explore two cases (a) Supplier Selection with Buyer Penalty for a Delay (SSPD) where the price of product increases with the delay. (b) Supplier selection with quantity reduction for a buyer delay (SSQRD). Three heuristic based supplier selection approaches are proposed and tested on randomly generated data sets. The proposed approaches show promising results.

Key words:

Housing Construction project, supplier selection, stochastic conditions, linear programming, heuristics, uncertainty

1.Introduction

In construction supply chain, there can be several risks associated with exogenous events such as delays in permit, inspection, material quality, supply and labor availability, etc. These events disrupt efficient functioning of supply chain. Some of these events are controllable. On the other hand there are several uncertainties due to factors like political issues, governmental regulations, changes in market, technological improvements and so on which are difficult to control.

Resource availability and work availability are two common limitations that constrain 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 a 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 2005).

In some industries raw material and supplies are required for a short duration, in which long term commitment with suppliers does not 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 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. sawmills/furniture companies) to buy from multiple suppliers in order to maintain competition and avoid various risks such as price, quality and delivery uncertainties (Awasthi *et al.,* 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 *et al.,* 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 crucial to complete the construction project on time and within the budget i.e. 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.

In today's highly competitive market, an effective supplier selection process and closer collaboration among buyers and suppliers are needed. In order to cope with market volatility and diversity, buyers have to establish and manage relatively flexible collaboration with the suppliers to be able to deal with unexpected market demands and thus reduce the dependence on the vendor (Ganesan, 1994). Suppliers usually offer attractive deals like better price and quality while they add some restrictions to their contracts such as minimum order size, limited capacity, lead time, etc. The minimum order size is mainly for economies of scale (to cover transportation and production set ups cost). The limitation on maximum acceptable quantity by the supplier is basically due to production or transportation capacities. These constraints make supplier selection problem (SSP) more challenging and complicated.

Supplier selection in construction industry differs from manufacturing industry. Usually manufacturing companies face uncertain product demand from their customers. These companies should apply supplier selection methods well-suited for stochastic demand conditions; on the other hand demand in construction projects can be considered stable and known (similar to make-to-order system) but due to various unexpected events the starting date of a specific phase of project may vary; so delivery time of material is subject to change. Consequently, proper suppliers should be selected to ensure availability of required material at building under condition of uncertain delivery time.

The research problem proposed in the paper is inspired by wood-base housing project construction industry where the demand for component items is fixed. Since this demand is communicated to suppliers well ahead of time, the delivery lead times are assumed to be fixed and same for all suppliers. In other words, buyer is interested in evaluating only those suppliers who match on the lead time and demand quantity requirements. If the construction project start date is delayed, then the suppliers can change the quantity or introduce penalty since the unsold wood may suffer quality loss if stored in open or poor storage conditions which may impact its financial value. Therefore, buyers have to anticipate these conditions if they foresee wood-base housing construction project will be delayed. Based on the suppliers(vendors') reaction towards these uncertainties in the project commencement dates, we explore two cases (a) Supplier Selection with Buyer Penalty for a Delay (SSPD) where the price of product increases with the delay. (b) Supplier selection with quantity reduction for a buyer delay (SSQRD).

The rest of the paper is organized as follows. In section 2, we present the literature review. Section 3 presents the supplier selection problem with buyer penalty for a delay and proposes algorithms SS-1 and SS-2 and their numerical applications. Section 4 presents the supplier selection problem with quantity reduction for a buyer delay and proposes algorithm SS-3 and its numerical experiments. The conclusions and future research directions are presented in section 5.

2. Literature Review

Nowadays project managers realize how risks associated with supply can have a huge influence on total cost of projects. Especially in construction industries, availability of resources at right time and with enough quantity is crucial in order to complete a project on time and within the budget. This shows the importance of supply risk management and supplier selection decisions.

Normally, supply risk management methods in a construction project, are categorized in two general groups: resource utilization optimization models and supplier selection models. Studies in the field of supply usage optimization lead to mathematical formulation for supply usage and show how resource (supply) planning can affect the project performance. Also applying more efficient supplier selection methods can decrease risks associated with supplies especially in the presence of supply chain uncertainties. Using appropriate supplier selection approaches is advantageous in engineering, procurement and construction (EPC) industries with high complexity plus high value of supplies. Figure 1 illustrates a categorization for supply risk management methods.

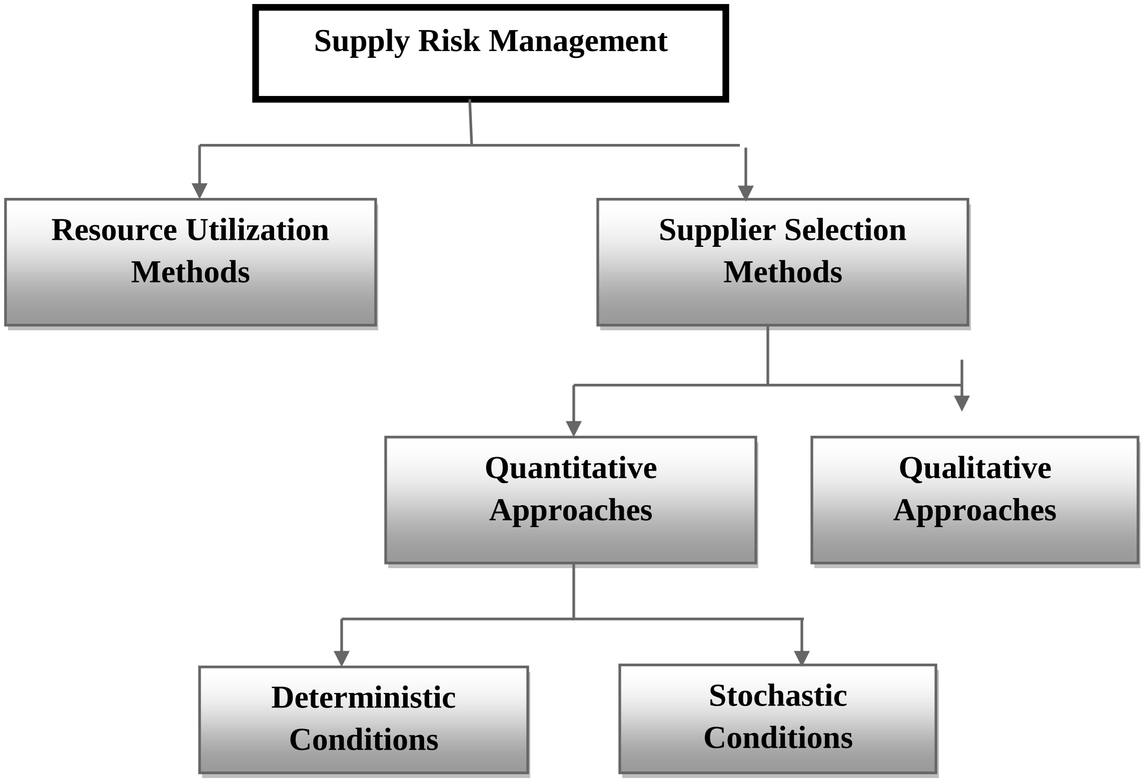

Figure 1: A categorization for supply risk management methods

We review some relevant papers in the field of supplier selection based on quantitative approaches. Quantitative approaches are most commonly used when numerical data is available. Most of the studies in the area of supplier selection emphasize on optimal quantity allocation. Factors such as demand quantity and lead time can be considered either stochastic or deterministic in the process of supplier selection. The studies reviewed in this part are divided in two main groups of deterministic conditions and stochastic conditions. In the deterministic case demand quantity and lead time are known and fixed. In the stochastic situation, mentioned factors are subject to change and may vary over time.

Also suppliers may have limited capacity or unlimited capacity. In the first case, it is assumed that the supplier has limited capacity while in the second case; supplier is able to provide requested quantity for any demand.

2.1 Deterministic 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 their 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 *et al.* (2008a) studied the same problem as Chauhan and Proth (2003) but instead of considering a fixed setup cost plus concave quantity discount for suppliers, Burke *et al.* (2008a) studied three different pricing schemes including linear discounts, incremental units discounts and all units discounts. Burke *et al.* (2008a) proposed a heuristic model to solve the problem. Burke *et al.* (2008b) considered a procurement problem where suppliers offer concave quantity discounts. Authors solved the continuous knapsack problem by minimization of a sum of separable concave functions. Burke *et al.* (2008b) identify several solvable special cases of the defined NP-hard procurement problem, and proposed an approximation scheme for the general problem. Burke *et al.* (2008c) 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 was developed to reach the optimal solution.

Chauhan *et al.* (2005) proposed an optimal algorithm based on dynamic programming for supplier selection problem (SSP) for single buyer. 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.

In a typical optimization problem there is one objective, but some time we may have multiple objectives of conflicting nature like objectives effective in supplier selection process and therefore managers explore the tradeoffs among the goals. Multi-objective methods are used in this case, which makes the decision maker able to incorporate his own experiences in supplier selection while there isn't such an opportunity for him in methods with an optimal solution; also the decision maker can easier see the effects of policy constraints (which purchasing department can directly influence) on the final selection. To deal with such problems where the objectives are in conflict with each other, we cannot find a solution that is optimal for all the objectives, so the term "optimal solution" will be replaced by "non-inferior" or non-dominant solution in which improving one objective will lead to degradation of at least another objective. There are two methods to provide non-inferior solutions: weighting method and constraint method. Weber and Current (1991) utilized the weighting method with a mixed-integer program to deal with three objectives: cost, delivery and quality. Also the authors put constraints on demand satisfaction (inequality), each supplier's capacity, and number of suppliers in deterministic demand conditions. Eventually "value paths" method is utilized to demonstrate the tradeoffs between objectives.

A single item, multi-supplier system with fixed demand, price-quantity discount considerations, suppliers' capacities constraints has been explored by Chang (2006). The author proposed a series of linearization strategies to obtain the global optimal values and used a mixed integer optimization approach to solve the procurement problem. Sawik (2010) explored supplier selection problem for a custom company in a make to order environment. The author 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 and 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 and 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 and Susuz (2009) 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 and Talluri (2008) as a tool for strategic supplier selection in the presence of risk measures and product life cycle considerations. Jolai *et al.* (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 and 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 *et al.* (2010) propose a scatter search algorithm for vendor selection problem. Yeh and Chuang (2010) studied supplier selection problem in a multi-product, multi-stage supply chain and propose a multi-objective genetic algorithm. Micheli *et al.* (2009) used a total cost of ownership (TCO) based approach. Wan and 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 utilized mathematical programming techniques 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 *et al.* (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.

2.2 Stochastic conditions

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

Abginehchi and 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 *et al.* (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 included 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 and 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 and Rittscher 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 and Zhang (2011) 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 that 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 *et al.* (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. Also 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 *et al.* (2009) used a similar heuristic method to Chauhan and 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 *et al.* (2009) is that Burke *et* *al.* (2007) only assigned quantities to the suppliers who must supply a positive quantity while Awasthi *et al.* (2009) identify and allocate the suppliers.

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.

2.3 Risk management in construction industry

Yates (1993) demonstrated development of the delay analysis system program for construction industry, its purpose, technical parameters and the program output. Odeh and Battaineh (2002) conduct survey study to identify the most important causes of delay in construction projects with traditional type contracts from the view point of construction contractors and consultants. They show owner interference, inadequate contractor experience, financing and payments, labor productivity, slow decision making, improper planning, and subcontractors as the top ten most important factors.

Sweis *et al.* (2008) explored the causes of construction delays in residential projects. They found financial difficulties faced by the contractor and too many change orders by the owner as the leading causes of construction delay. Assef and Al-Hejji (2006) did a survey on time performance of construction projects and identified “change order” as the most common cause of delay by contractors, consultants and owners. Luu *et al.* (2009) apply Bayesian belief network (BBN) to quantify the probability of construction project delays in a developing country. A questionnaire survey of 166 professionals showed that financial difficulties of owners and contractors, contractor's inadequate experience, and shortage of materials are the main causes of delay on construction projects in Vietnam.

Baloi and Price (2003) identified major global risk factors affecting cost performance of a construction project. Different decision-making technologies such as classical management science techniques and DSSs, KBSs were explored and evaluated. They show fuzzy set theory as a viable technology for modeling, assessing and managing global risk factors affecting construction cost performance.

It can be seen from above that although the problem of supplier selection has been widely researched under deterministic and stochastic demand condition, yet there is rare literature on the consideration of uncertainty in the starting date of a construction project on the supplier selection process. This is the motivation for research conducted in this paper.

2.4 Research Gaps

It can be seen from above literature review that although several approaches have been proposed for supplier selection under deterministic and stochastic conditions, however, very few analytical works are done in the context of construction industry. The number is even less for wood-base construction projects such as housing. Besides, very few researchers tried to investigate supplier selection under buyer penalties (e.g. quantity or price reduction, order cancellation) which can happen in the case of limited number of suppliers in perishable goods industry such as wood, fresh foods. This is the challenge we are addressing in this paper.

3. **Supplier Selection with Buyer Penalty for a Delay (SSPD)**

In this section, we consider the case in which suppliers offer a new pricing scheme as a penalty for the delay (SSPD) to the buyer. The objective is to select a set of suppliers, from a pool of pre-qualified suppliers, which minimizes the expected purchasing cost.

3.1 Assumptions

- The demand is known and fixed.
- The delivery lead time is fixed and assumed to be same for all suppliers.
- The contractor knows the probability distribution (f) of the project delay or the expected starting date of the project.
- Suppliers provide material for a single phase of the project.
- k delay scenarios (S) are considered. Each delay scenario $s \in S$ has a modified price from suppliers.
- Suppliers supply the material very close to the project starting date, even in the case of delay; we do not consider inventory holding costs.
- Transportation costs are included in the prices quoted by the suppliers.

3.2 Mathematical Formulation

A set of suppliers $N= \{1,2,..,n\}$ can deliver raw material to the site of a construction project. In the current construction phase demand quantity is constant and equal to D. There are two constraints that apply to any supplier $i \in N$:

- The minimum quantity that supplier *i* prepares to deliver for economical reason is denoted by m_i.
- The maximum quantity that supplier i is able to deliver due to restrictions in production capacity, or reserved capacity for other customers and restricted time lines. This quantity is denoted by M_i.

Thus, the quantity $x_i, i \in N$ delivered to the building site is such that $x_i \in \{0\} \bigcup [m_i, M_i]$

We suppose suppliers' prices are discrete function of delay. The price quoted per unit by supplier $i \in N$ for delay scenario $s \in S$ is denoted by $P_{i,s}$.

Also the discrete probability distribution function for delay *(f)* is known.

The mathematical formulation of SSPD is presented as follows:

$$Minimize\ Z = \sum_{i \in N} \sum_{s \in S} P_{i,s} x_i f_s \qquad (1)$$

$$\sum_{i \in N} x_i = D \qquad (2)$$

$$m_i I_i \le x_i \le M_i I_i, \forall i \in N \qquad (3)$$

$$I_i \in \{0,1\} \qquad (4)$$

The objective is to select order quantity, x_i corresponding to supplier *i* to minimize the expected total purchasing cost (1). Constraint (2) assures that the summation of ordered quantities is equal to demand; constraint (3) makes sure that the order quantity, for a selected supplier, lies between the corresponding minimum order size m_i and the maximum permitted M_i. Equation (4) is used to define binary variables, I_i which ensure that either a supplier delivers a quantity or do not supply at all.

Proposition 1: The problem $SSPD$, is NP-hard even if all suppliers are quoting the same unit-selling-price.

Proof: The proof we present here is along the lines of proof presented in Chauhan *et al*. (2002). Assume that a polynomial time algorithm exists for *SSPD*. Now consider the special case of problem *SSPD* where delivery time of material is certain and each supplier supplies a single quantity i.e. minimum order quantity, say m_i, is equal to M_i. In this case each supplier either supplies m_i or nothing ($x_i \in \{0, m_i\}$). Furthermore, because of the unique selling price the whole problem reduces to selecting a combination of suppliers who can supply, collectively, *D* units where *D* is the given demand quantity. Now the remaining problem can be expressed as follows:

$$\sum_{i \in N} m_i I_i = D \qquad (5)$$

$$I_i \in \{0,1\}, \forall i \in N \qquad (6)$$

This problem is NP-hard since the partition problem (Garey and Johnson, 1979) is a special case of (5) and (6).

Proposition 2: In an optimal solution to *SSPD* at most one supplier may not satisfy the following $x_i \in \{0\} \cup \{m_i, M_i\}$.

Assume that in an optimal solution supply corresponding to two suppliers *j* and *k*, is such that the condition of Proposition 2 is not satisfied i.e. $m_j < x_j < M_j$ and $m_k < x_k < M_k$.

Based on the objective function defined in equation 3.1, we denote the coefficient of order quantity x_i with β_i:

$$x_i \sum_{s \in S} P_{i,s} f_s = x_i \beta_i \tag{7}$$

Now consider coefficients β_j and β_k, one of the following can exist:

$\beta_j < \beta_k$ or $\beta_j > \beta_k$ or $\beta_j = \beta_k$

Assume that the first case is true and therefore increasing the order size of supplier j by δ units: $\delta > 0, \delta = \min(M_j - x_j, x_k - m_k)$ and reducing the order size of supplier k by δ units will improve the solution. We can follow the same approach in the other cases. In the case that $\beta_j = \beta_k$, either of supplier j or k can obtain a value of restrictions on order sizes. This completes the proof.

3.3 Solution Approach for SSPD

Since SSPD is a NP-hard problem it is less likely that an exact algorithm could guarantee a solution in polynomial run time. Therefore, we propose two heuristic algorithms SS-1 and SS-2 in order to find efficient solution for SSPD. These algorithms are explained as follows.

Algorithm SS-1

Arrange suppliers in ascending order of their expected prices. Let us denote the ordered providers by $1, 2, \dots, n$. Consider d as a variable which will be updated, and initialize $d = D$.

Expected prices are calculated as follows:

$$p_{avg_i} = \sum_{s\in S} P_{i,s} \times f_s;\ \forall\, i = 1, 2, \dots, n$$

1. For $i = 1, 2, \dots, n$

1.1 If $d > M_i$, then Set $x_i = M_i$ and Compute $d = d - x_i$.

1.2 If $d \in [m_i, M_i]$, then Set $x_i = d$ and Compute cost of assignment. Stop.

1.3 If $d < m_i$, set $i^* = i$ and go to part 2.

2. For $i = i^*, i^* + 1, \dots, n$

2.1. Allocate m_i to supplier i

2.2. Assign the remaining quantity among suppliers $\{1, \dots, i^*\}$ in the most economical way; this involves part 1 of the algorithm again (see appendix A).

2.3. If the assignment is successful, compute the cost for the assignment. Keep the assignment in the memory if the cost of this assignment is better than all previous assignments.

Proposition 3: If the algorithm terminates at 1.2 (without entering part 2), then the solution is optimal.

Proof: In such cases the solution always satisfies the Proposition 2. Since the suppliers are arranged in the increasing order of their price, the solution obtained is the minimum cost solution.

Algorithm SS-2

In algorithm SS-2 for each delay scenario, first we arrange suppliers in increasing order of their quoted unit prices, then by using similar method of SS-1 the best solution for each delay scenario will be computed and finally we will select the solution with minimum cost.

1. For each delay scenario $s \in S$,

 1.1 Arrange suppliers in ascending order of their unit prices for delay scenario s.

 1.2 Use algorithm SS-1 to compute the best assignment say A_s.

 1.3 Compute the expected cost of the assignment A_s and if it is less than cost of all previous assignments, keep the assignment in the memory as the best assignment.

3.4 Numerical Application

In order to evaluate the performance of the proposed algorithms SS-1 and SS-2, 1300 experiments were done and the results of these two algorithms were compared with optimal solution. The two algorithms SS-1 and SS-2 and the optimal solution were modeled in C++ using Visual Studio 2008. All required data including supplier quoted-unit-selling prices for each delay scenarios, order size limitations, delay scenario probabilities and demand quantity were randomly generated. The details of the randomly generated data set are provided as follows:

Random data generation

(i) Number of delay scenarios (k) is a random number between 2 and 5.

(ii) Probability of each scenario is generated randomly using the following formula:

$$f_s = Rand(0, 1 - \sum_{j=1}^{s-1} f_j) \qquad \text{(A)}$$

(iii)The minimum acceptable order quantities (m_i) are generated at random between zero and 20 and maximum acceptable order quantities (M_i) is equal to m_i plus an integer random number between 5 and 25.

(iv) In order to generate quoted unit prices $(P_{i,s})$ randomly we followed next steps:

Initialize $price = 0$ (Consider a function called $GetRandomBetween(a, b)$ which generates a random number between a and b).

For every supplier $i \in N$:

1) $price = price + GetRandomBetween(0.5, 1)$
2) $P_{i,0} = price$

Then for each delay scenario $s \in S$:

3) $P_{i,s} = P_{i,s-1} + price * GetRandomBetween(0,3.1)$

(v) Demand quantity (D) is an integer random number between summation of all m_i $(i \in N)$ and sum of all M_i $(i \in N)$:

$$D = Rand(\sum_{i \in N} m_i, \sum_{i \in N} M_i)$$

Several tests were conducted with problem size (number of suppliers) ranging from 3 until 15. For each problem size, 100 tests were done. The relative error for each experiment of SS-1 and SS-2 was calculated using the following formula:

=(Cost of SS1(or SS2) – Cost of Optimal Solution)*100/Cost of Optimal Solution (8)

where the Optimal Solution was generated through CPLEX.

Then, we calculated the mean and standard deviation of relative errors for 100 experiments for every problem size. Table 1 provides the mean relative error and standard deviation for each problem size (from 3 to 15) using SS-1 and SS-2. It can be seen in Table 1 that both approaches are quite effective in obtaining a very good solution (mean relative error is less than 1%), however it seems SS-1 is offering much closer solutions to optimal solution than SS-2 (Table 1) based on randomly generated problems. In algorithm SS-1 we allocate quantities based on the expected price which could be misleading and it is possible that expected price may leave some good/competitive suppliers out of the selection system. In other words both algorithms have their own advantage.

Number of Suppliers	**Mean Relative Error SS-1 (%)**	**Standard Deviation of Relative Error SS-1**	**Mean Relative Error SS-2 (%)**	**Standard Deviation of Relative Error SS-2**
3	0	0	0	0
4	0.0051	0.0517	0.0184	0.184
5	0	0	0.0065	0.065
6	0.0109	0.0991	0.0104	0.098
7	0.0108	0.0539	0.0290	0.148
8	0.0146	0.0761	0.0293	0.275
9	0.0374	0.2034	0.0110	0.069
10	0.0123	0.0864	0.0451	0.174
11	0.0109	0.0736	0.063	0.285
12	0.0255	0.2225	0.0985	0.3880
13	0.0139	0.0973	0.0615	0.209
14	0.0262	0.1465	0.0836	0.332
15	0.0013	0.0131	0.052	0.2115

Table 1: Mean relative error and standard deviation of relative error for SS-1 and SS-2

Table 2 shows the mean relative error for SS-1 and SS-2. It can be seen that algorithm SS-1 on average lead to lower relative error than the results from using algorithm SS-2.

Mean Relative Error (%)	
SS-1	0.013
SS-2	0.039

Table 2: Mean relative error for results of SS-1 and SS-2 algorithms

4.Supplier Selection with Quantity Reduction for a Buyer Delay (SSQRD)

In this section we investigate how decreasing the signed quantity by suppliers after the event of delay can affect the purchasing decision making at the time of signing a contract with suppliers. The objective is to select a set of suppliers, from a pool of pre-qualified suppliers, which minimizes the expected purchasing cost.

4.1Assumptions

- A set of pre-qualified suppliers are available to supply required material at a building site.
- Market has no limitations on order quantity and its price is fixed.
- Demand is known and fixed.
- Delivery lead time is assumed to be fixed and is the same for all suppliers.
- The building contractor (buyer) knows the probability distribution (f) of the project delay or the expected starting date of the project.
- Suppliers under consideration are associated with only one phase of the construction project.
- Suppliers provide material with the same acceptable quality level.
- The suppliers may impose restrictions on the minimum and the maximum order size.
- The unit selling price quoted by any supplier is fixed and may differ from each other.

In this case, the supplier reduces the promised quantity, with a known reduction factor on project delays or changes in demand. We consider k delay scenarios(S). Suppliers provide the buyer (constructor) with the reduction factor $(1-\alpha_{i,s})$ of promised quantity regarding each delay scenario $s \in S$. We consider a discrete distribution for project delay and therefore the suppliers' quantity reduction functions are discrete as well.

The objective in SSQRD is to minimize the expected purchasing cost. The purchasing cost only includes the mean cost that the buyer pays to the suppliers. It is assumed that suppliers are able to deliver material very close to project starting date, so inventory cost is excluded. We also assume transportation cost is included in the suppliers' quoted unit prices. The goal is to acquire specific quantities from a group of suppliers and buy the remaining quantity from market at a minimum possible cost.

4.2 Mathematical Formulation for SSQRD

Following section 2.2 notations, the quantity x_i, $i \in N$ delivered to the building site is given by $x_i \in \{0\} \cup [m_i, M_i]$.The quantity ordered from market in scenario s is given by $x_{M,s}$. For delay scenario $s \in S$ in delivery time of material, supplier $i \in N$ will decrease the promised quantity by a reduction factor $1 - \alpha_{i,s}$. The price quoted per unit by supplier $i \in N$ is denoted by P_i and is fixed. If the set of selected suppliers are not able to satisfy the demand, the contractor (buyer) will fulfill the missing quantity from the market at price P_M, where $P_M \geq P_i, i \in N$.

The discrete probability distribution function for delay (f) is known.

The mathematical formulation of SSQRD is presented as follows:

$$MinZ = \sum_{s \in S} f_s (\sum_{i \in N} P_i x_i \alpha_{i,s} + P_M x_{M,s}) \quad (9)$$

Subject to:

$$\sum_{i \in N} \alpha_{i,s} x_i + x_{M,s} \geq D, \forall s \in S \tag{10}$$

$$m_i I_i \leq x_i \leq M_i I_i, \forall i \in N \tag{11}$$

$$I_i \in \{0,1\}, \forall i \in N \tag{12}$$

The objective is to select order quantity, x_i corresponding to supplier i for minimizing the expected total purchasing cost (9). Constraint (10) assures that sum of ordered quantities is at least equal to demand quantity; Constraint (11) makes sure that the order quantity, x_i for a selected supplier, lies between the corresponding minimum order size m_i and the maximum permitted M_i. Constraints (12) imposes the restrictions on the value of variables I_i .

4.3 Basic Results

In the case of continuous probability distribution, following propositions can be observed:

Proposition 1: For SSQRD, in the case of single supplier with unit price P, we show the optimal order quantity (Q) should satisfy the following condition:

$$\int_{0}^{\frac{Q-D}{\alpha}} f(t)dt = \frac{P_M}{P_M + P} \quad \text{or} \quad \text{Probability}\left(t < \frac{Q-D}{\alpha}\right) = \frac{P_M}{P_M + P}$$

Proof: Consider a single supplier that decreases the agreed quantity by α units in the event of each delay scenario (α is a linear reduction factor and its unit is unit of quantity/time unit).

The buyer has signed a contract for delivery of Q units of product at the agreed delivery time. Q is the appropriate quantity to cover the delay $t = \frac{Q-D}{\alpha}$. In other words Q is sufficient to absorb the demand delay of t periods.

For simplicity of the mathematical calculation, we assumed that the probability distribution function is a continuous function of delay and denoted by $f(t)$. We assumed $f(t)$ follows any continuous distribution functions.

The cost C expresses the cost of excess product as well as cost of product shortage.

Also the order quantity Q satisfies the following constraint:$Q \geq D$.

$$C = \int_0^{\frac{Q-D}{\alpha}} P(Q-D-\alpha t) f(t) dt + \int_{\frac{Q-D}{\alpha}}^{\infty} P_M (D-Q+\alpha t) f(t) dt$$

$$\frac{\partial C}{\partial Q} = \frac{1}{\alpha} \times 0 + \int_0^{\frac{Q-D}{\alpha}} Pf(t)dt - P_M \frac{1}{\alpha} \times 0 + \int_{\frac{Q-D}{\alpha}}^{\infty} -P_M f(t)dt$$

$$\frac{\partial C}{\partial Q} = 0 \text{ (For first order optimality condition)}$$

$$\int_0^{\frac{Q-D}{\alpha}} Pf(t)dt - \int_{\frac{Q-D}{\alpha}}^{\infty} P_M f(t)dt = 0$$

$$P\int_0^{\frac{Q-D}{\alpha}} f(t)dt - P_M\left[1-\int_0^{\frac{Q-D}{\alpha}} f(t)dt\right] = 0$$

$$(P+P_M)\int_0^{\frac{Q-D}{\alpha}} f(t)dt = P_M$$

$$\int_0^{\frac{Q-D}{\alpha}} f(t)dt = \frac{P_M}{P_M+P}$$

Observations:

I. In the case of single supplier problem, if market price is equal to supplier's price $(P_M = P)$, then we have to buy enough quantity to cover the periods which brings the cumulative probability up to 50%.

$$P = P_M$$

$$\int_0^{\frac{Q-D}{\alpha}} f(t)dt = \frac{P_M}{P_M+P} = 0.5$$

II. If the product of interest is much more expensive in market than buying it from supplier, then we have to buy enough quantity to cover all the possible delays.

$$P_M \gg P$$

$$\int_0^{\frac{Q-D}{\alpha}} f(t)dt = \frac{P_M}{P_M+P} \rightarrow 1$$

III. In the case of multiple suppliers, if suppliers' quoted prices have been arranged in ascending order as follows $P_1 < P_2 < \cdots < P_n$, then

$$\int_0^{\frac{Q_1 - D}{\alpha}} f(t)dt = \frac{P_M}{P_M + P_1} = b_1$$

$$\int_0^{\frac{Q_n - D}{\alpha}} f(t)dt = \frac{P_M}{P_M + P_n} = b_n$$

Since $P_1 < P_n$ then $b_1 > b_n$.

Since the effective price must be between P_1 and P_n, the optimal order quantity should cover delays which brings the cumulative probability to β^*, where $b_n \leq \beta^* \leq b_1$.

IV. Assume there are two suppliers offering the same price $P_1 = P_2$, and only one has to be selected and suppose $\alpha_1 > \alpha_2$, then the quantity we order from supplier 1 (Q_1) should be always greater than the quantity we order from supplier $2(Q_2)$.

Proof: Optimal order quantity must satisfy the following relation:

$$\int_0^{\frac{Q - D}{\alpha}} f(t)dt = \frac{P_M}{P_M + P}$$

Let's assume $\alpha_1 > \alpha_2$, i.e. $\alpha_1 = \alpha_2 + \delta$, then:

$$\int_0^{\frac{Q_1 - D}{\alpha_1}} f(t)dt = \int_0^{\frac{Q_2 - D}{\alpha_2}} f(t)dt = \frac{P_M}{P_M + P}$$

This implies

$$\frac{Q_1 - D}{\alpha_1} = \frac{Q_2 - D}{\alpha_2}$$

$$Q_1 - Q_2 = \frac{\delta}{\alpha_2}\,(Q_2 - D)$$

$\frac{\delta}{\alpha_2}$ is a positive constant. Since market price is always bigger than supplier's price:

$Q_1, Q_2 \geq D$. The right hand side of the above equation is positive so the left hand side should be positive, and thus: $Q_1 > Q_2$.

4.4 Solution Approach for SSQRD

Firstly, arrange suppliers based on their effective unit prices. Effective unit price for supplier i is calculated as follows:

Compute the expected supply(es_i) for supplier i as minimum between demand quantity (D) and supplier i maximum acceptable order size (M_i).

$es_i = minimum\ (D, M_i)$

Then calculate the effective unit price (eup_i) as follows:

$$eup_i = (\sum_{s \in S} f_s(es_i \times \alpha_{i,s} \times P_i + es_i \times (1 - \alpha_{i,s}) \times P_M))/es_i$$

In the next step, based on observation III, we determine the delay scenarios that we have to examine say $s \in R$.

Define $d = D$.

In this approach we assume market as $(n+1)^{th}$ supplier with no limitation on minimum and maximum order size.

For each delay scenario $s \in R$ compute the following:

1 For $i = 1, 2, \ldots, n+1$

(a) If $\frac{d}{\alpha_{i,s}} > M_i$ then Set $x_i = M_i$ and Compute $d = d - \alpha_{i,s}\, x_i$.

(a) If $\frac{d}{\alpha_{i,s}} \in [m_i, M_i]$, then Set $x_i = \frac{d}{\alpha_{i,s}}$ and Compute cost of assignment and stop.

(a) If $\frac{d}{\alpha_{i,s}} < m_i$, set $i^* = i$ and go to Part2.

2. End of loop i.

3. For $i = i^*, i^* + 1, \ldots, n+1$

3.1. Allocate m_i to supplier i

3.2. Assign the remaining quantity among suppliers $\{1, \ldots, i^*\}$ in the most economical way; this involves Part 1 of the algorithm again (see appendix B).

3.3. If the assignment is successful, compute the cost for the assignment. Keep the assignment in the memory if the cost of this assignment is better than all previous assignments.

4.5 Numerical Application

We conducted two set of experiments:

4.5.1 First set of experiments

The first set of experiments involves a set of 600 randomly generated experiments for SSQRD. In 88.6% of the cases the optimal solution for SSQRD is an optimal solution for one of the delay scenarios. These experiments were run in Visual Studio C++ 2008 for a range of 4-15 suppliers. For each number of suppliers, 50 tests were generated. The following paragraphs explain the details of the random data that have been generated for this study.

Random data generation

(i) Number of delay scenarios is a randomly generated number between 2 and 5.

(ii) Probability of each delay scenario is calculated using (A)

(iii) Reduction factor of all suppliers for the first delay scenario is equal to zero. For each supplier the reduction factor for delay scenario $s \in \{2, 3, \dots, k\}$ is randomly generated between the successive previous scenario reduction factor and one.

(iv) Each supplier's minimum order size m_i is a random number between zero and 20. Maximum order size of supplier i is equal to summation of m_i with a random number between five and 25.

(v) Demand quantity is generated randomly between summation of all minimum acceptable order sizes (m_i) and summation of all maximum acceptable order sizes (M_i).

(vi) Supplier i's quoted unit price (P_i) is equal to the price of previous successive supplier (P_{i-1}) plus a random number between 0.5 and 5.

Consider a function called $GetRandomBetween(a, b)$ which generates a random number between a and b. Initialize variable $price = 0$, this variable will be updated.

For $i \in N$:

1) $price = price + GetRandomBetween(0.5, 5)$

2) $P_i = price$

(vii) Market price is equal to a randomly generated number between the maximum unit price (P_n) and multiplication of that to three $(3P_n)$.

4.5.2 Second set of experiments

In the second set of experiments, we evaluate the performance of algorithm SS-3. 1300 random problems were generated and solved by means of SS-3, and then the results were compared with the optimal solutions of each problem. The exact algorithm is modeled by linking a C++ program in Visual Studio 2008 to ILOG CPLEX 11.2 software. Also the proposed algorithm SS-3 is modeled by a C++ program in Visual Studio 2008.

One hundred randomly generated problems were solved for each problem size ranging from three to fifteen suppliers. The following paragraphs provide details on the random data used in the study.

Random data generation

(i) Number of delay scenarios (k) is a random number between 2 and 6.

(ii) Probability of each delay scenario is calculated using (A).

(iii)(m_i) are generated randomly between zero and 10. (M_i) is equal to m_i plus a random integer number between 10 and 25.

(iv)In order to generate supplier i quoted unit price (P_i) randomly$(i \in N)$, next steps were followed:

Consider a function called $GetRandomBetween(a, b)$ which generates a random number between a and b. Initialize variable $price = 5$, this variable will be updated.

For $i \in N$:

3) $price = price \times GetRandomBetween(1.01, 1.25)$

4) $P_i = price$

(v) Market price is generated randomly as follows:

$$Market\ price = P_n + GetRandomBetween(1,2) \times P_n$$

(vi)Demand quantity (D) is an integer random number between summation of all m_i $(i \in N)$ and sum of all M_i $(i \in N)$.

(vii) Reduction factor $(1 - \alpha_{i,s})$ of all suppliers for the first delay scenario is equal to zero. For each supplier the reduction factor for delay scenario $s \in \{2, 3, \dots, k\}$ is randomly generated between one and the successive previous scenario reduction factor.

Average of relative errors and standard deviation of the relative error were calculated. Table 3 provides the results of mean relative error and standard deviation for each problem size (3-15) using SS-3. It can be seen that the total average relative error of algorithm SS-3 is equal to 2.3% . Since the maximum mean relative error is 3.69% (which is less than 5%), SS-3 proves to be efficient in providing solutions close to optimal solution.

Number of Suppliers	Mean Relative Error (%)	Standard Deviation
3	2.396	7.946
4	1.751	5.936
5	1.898	6.695
6	2.177	5.602
7	3.696	9.184
8	2.451	7.496
9	2.213	5.239
10	2.609	7.566
11	2.160	7.048
12	2.902	9.415
13	1.863	5.694
14	1.449	2.860
15	2.312	4.946

Table 3: Mean relative error and standard deviation of relative error for SS-3

5. Conclusions and Future Works

In this paper, we investigate the problem of managing supply under uncertain starting date for wood-base construction (housing) projects. Two cases are considered for construction project supplier selection under uncertain starting date. In the first case, we address Supplier Selection with Buyer Penalty for a Delay (SSPD) where the price of product increases with the delay whereas in the second case we perform supplier selection with quantity reduction (SSQRD) for a buyer delay. Heuristic based solution approaches are proposed and tested on randomly generated data sets. The results of proposed approaches are compared with the optimal results. In most of the cases the average error is less than 1%. From the solution quality, we can conclude that algorithms are capable of obtaining solutions very close to the optimal solutions.

In the current work we assume fixed price and single product. In reality suppliers give discounts on quantity. In future works, we will extend the model to incorporate various types of quantity discounts such as non-linear price discount. Moreover, a fixed set up cost can be added to the cost function of suppliers.

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Appendix A

In algorithm SS-1 if the problem enters part 2, after allocating m_{i^*} to supplier i^*, SS-1 will distribute the remaining demand $(d = D - m_{i^*})$ among suppliers $i = 1, \ldots, i^*$ in the most economical way.

The following steps assign the suppliers in the most economical way:

For each supplier $i \in \{i^*, \ldots, n\}$:

1. Initialize $flex = 0$.
2. Allocate m_i to supplier $i: x_i = m_i$.
3. Calculate the flexibility for supplier i: $flex = flex + (M_i - m_i)$.
4. Compute $d = D - m_i$.
5. Call the algorithm SS-1 with following additional conditions.

Allocate d among supplier $\{1, 2, \ldots, i - 1\}$ using Part1 of algorithm SS-1. If the condition # 1.2 happens compute the cost for the assignment and continue.

In the case of condition # 1.3:

If $d \leq flex$ adjust d in x_i: $x_i = m_i + d$. Compute the cost of the assignment and keep it if the cost is better than previous allocations (if any).

Note: d may be assigned to more than one supplier with the flexibility (that is $m_i \leq x_i < M_i$).

Appendix B

In algorithm SS-3 if the problem enters part 2, after allocating m_{i^*} to supplier i^*, SS-3 will distribute the remaining demand $(d = D - \alpha_{i^*,s}\, m_{i^*})$ among suppliers $i = 1, \dots, i^*$ in the most economical way in the following steps:

For each supplier $i \in \{i^*, \dots, n+1\}$:

1. Initialize $flex = 0$.
2. Allocate m_i to supplier$i$: $x_i = m_i$.
3. Calculate the flexibility for supplier i: $flex = flex + \alpha_{i,s}(M_i - m_i)$.
4. Compute $d = D - \alpha_{i,s} m_i$.
5. Call the algorithm SS-3 with following additional conditions

Allocate d among supplier $\{1, 2, \dots, i-1\}$ using Part1 of algorithm SS-3. If the condition # 1.2 happens compute the cost for the assignment and continue.

In the case of condition # 1.3:

If $d \leq flex$ adjust d inx_i: $x_i = m_i + \frac{d}{\alpha_{i,s}}$. Compute the cost of the assignment and keep it if the cost is better than previous allocations (if any).

And if $d > flex$, this means we identify one more supplier which cannot accommodate the remaining amount of demand. We set this new supplier as $i^*$and follow again the same steps (1-5 of Appendix).

Note: d may be assigned to more than one supplier with the flexibility (that is $m_i \leq x_i < M_i$).