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A mixed-integer non-linear program to model dynamic supplier selection problem

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ABSTRACT

In a highly competitive scenario, suppliers play a vital role in making a business organization successful. Business of any organization is continuous process and therefore the supplier selection is also dynamic in nature. This is quite natural as the organization's demand; supplier's capacity, quality level, lead time, unit part cost and fixed transportation cost of supplier varies with time. Therefore, supplier identified for one period may not necessarily be same for the next period to supply the same set of parts. Hence, the supplier selection problem is highly dynamic in real practice. In this paper, a mixed-integer non-linear program (MINLP) is developed to address the dynamic supplier selection problem (DSSP). To validate the proposed MINLP data are generated randomly. A numerical illustration is also provided to demonstrate the proposed MINLP using LINGO.

1. Introduction

In today's highly competitive and dynamic environment, business organizations are forced to optimize their business operations to meet the increasing customer's demand within due time keeping desired quality level in minimum cost. For any organization to remain competitive, it has to work closely with its supply chain partners i.e. suppliers. Thus, now-a-days supplier plays an important role in an organization for timely manufacturing finished good products which is directly shipped to the markets. Hence, the selection of suppliers becomes an important aspect of any business organization. In any supplier selection process, generally six main decision processes takes place viz: (1) make or buy, (2) supplier selection, (3) contract negotiation, (4) design collaboration, (5) procurement, and (6) sourcing analysis. Of these six decision process, supplier selection is one of the most vital and crucial decision which not only responsible of supplying the parts but also responsible in keeping the organization in a competitive mode. Selection of suppliers becomes more important when an organization has to select the supplier for more than one period and when the supplier's capacity, their quality level, lead time, and various cost parameters also vary. Hence, the supplier selection for multi-period, multi-parts, and multi-source is a widely occurring phenomena in a large business organization while keeping the desired quality level and least lead time. In literature it is popularly known as *Dynamic Supplier Selection Problem (DSSP)*.

In a DSSP, a set of suppliers is chosen for each period from the pool of suppliers. The main issues of DSSP are: (1) *Which part to be procured (or ordered) from which supplier(s)*? (2) *In what quantities these parts to be procured.* (3) *In which period the supplier will be selected to supply these parts*. DSSP differs from a *Traditional Supplier Selection Problem* (TSSP) where all the suppliers can fully meet the organisations' requests in terms of quantity, quality, delivery, etc. The only decision concerns the identification of the best supplier or the ranking of the suppliers. Whereas in DSSP none of the suppliers is able to satisfy the organizations' total demand due to various limitations at the supplier's end such as its capacity, quality level, delivery time, price, etc. In these circumstances the DSSP is threefold: *Supplier Selection*, Part *Quantity* and *Time Period*. Order quantities of the part and supplier choice are closely interrelated. Incorporating the decision to schedule orders over time with the supplier selection significantly reduces cost for entire planning horizon. On considering a multi-period horizon, one or more than one suppliers could be selected in each period to meet the organisation's requirement (or demand). The problem of selecting suitable suppliers is not a new problem and a great number of conceptual and empirical works have been published. Most of the models available in the literature of supplier selection deal with the case of single-period and ranking of the best supplier among the existing suppliers which is capable of meeting all the demand. In this paper, authors made an attempt to address the supplier selection in multi-period for multi-parts from multi-source. Hence, the paper propose MINLP to model DSSP.

The remainder of the paper is organized as follows: In Section 2, past work related to supplier selection problem is reviewed. In Section 3, DSSP is defined. Section 4 presents the MINLP formulation of DSSP. To demonstrate the MINLP, two illustrative examples are provided in Section 5 followed by conclusion and the directions for future research.

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2. Related work

Plethora of literatures on supplier selection or vendor selection problems are available whereas the DSSP considering multi-period multi-parts multi-source is not adequately discussed in the past. For the detailed review on supplier selection problems papers by Weber, Current, and Benton (1991), Boer, Wegen, and Telgen (1998), Wadhwa and Ravindran (2007), Chan & Chan (2004) and Ware, Singh, and Banwet (2012) can be referred. In past several methodologies have been proposed for the supplier selection problem but many of them only discusses the case of TSSP. In the TSSP, suppliers are ranked and the top ranked supplier is supposed to be same throughout the entire planning horizon unless it is re-ranked or re-assessed. The past work on supplier selection is broadly classified into two categories viz. (1) Quantitative models and (2) Qualitative models. In the category (1) numerous quantitative models such as linear programming, mixed-integer linear program, mixed-integer non-linear program, dynamic programming, multi-objective programming (Amin, Razmi, & Zhang, 2011; Dempsey 1978; Shipley, Colin, & Scott, 1991; Weber and John, 1993; Feng, Wang, & Wang, 2001; Ghodsypour & O'Brien, 2001; Masella & Rangone, 2000; Ghodsypour & O'Brien, 1998; Guneri, Yucel, & Ayyildiz, 2009, 1998; Weber and John, 1993; Demirtas & Ustun 2008; Ozgen, Onut, Gulsun, Tuzkaya, & Tuzkya, 2006; Razmi & Rafiei, 2010; Sanayei, Mousavi, Abdi, & Mohaghar, 2008; Thomas & Srinivas, 2008). Masella and Rangone (2000) proposed four different vendor selection systems depending on the timeframe (short term versus long term) and on the content (logistic versus strategic) of the co-operative customer/supplier relationships. Ding, Benyoucef, and Xie (2005) presented a Genetic Algorithm (GA) based optimization methodology for the supplier selection. Cakravastia and Takahashi (2004) proposed a multi-objective model to the process of supplier selection and negotiation that considers the effect of these decisions on the manufacturing plan. Liu, Ding, and Lall (2003) used data envelopment analysis (DEA) to compare the performance evaluation of different supplier for best selection. Aksoy and Ozturk (2011) works on supplier selection and performance evaluation in just-in-time production environments. Fuzzy DEMATEL method used for developing supplier selection criteria by Chang, Chang, and Wu (2011).

Wang and Chin (2008) used the advantages of Analytical Hierarchical Process (AHP) and preemptive goal programming to incorporate both quantitative and qualitative factor in supplier selection problem. For partner selection criteria in strategic alliances is explained by Wu, Shih, and Chan (2009) using the analytic network process. Application of fuzzy network process for supplier selection in a manufacturing organization discussed by Vinod, Ramiya, and Gautham (2011).

Similarly, in the category (2) many qualitative models such as AHP (Saaty, 1980, 1990; Narasimhan, 1983; Nydik & Hill, 1992), Fuzzy-AHP and weighted point method (Timmerman, 1986), matrix approach (Gregory, 1986), vendor performance matrix approach (Soukup, 1987), vendor profile analysis (Thompson, 1990), Analytical Network Process (ANP) (Bayazit, 2006; Chia-Wei and Allen, 2009; Demirtas & Ustun, 2009; Gencer and Gurpinar, 2007), TOPSIS and Fuzzy-TOPSIS (Boran, Genc, Kurt, & Diyar 2009; Shahanaghi & Yazdian, 2009; Wang, Cheng, & Chen, 2009;Kelmenis & Askounis, 2010) have been proposed by various researchers in the past to solve TSSP. Ghodsypour and O'Brine (1998) proposed integration of an AHP and linear programming to consider both tangible and intangible factors in selecting the best suppliers. Chan and Chan (2004) developed a model for TSSP applying AHP and quality management system principles. Choy, Lee, and Lo (2002) used the case based reasoning approach for efficient supplier selection to enhance the performance of the selection as compared to traditional approaches. Lee, Ha, and Kim (2001) proposed the supplier selection and management system that includes purchasing strategy system, supplier selection system and supplier management system.

Lee (2009) provides a fuzzy supplier selection model with the consideration of benefits, opportunities, costs and risks. A combined methodology for supplier selection and performance evaluation shown by Mithat, Cuneyt, and Cemal (2011).

It is observed that the TSSP is unable to capture the information of suppliers for all periods in a planning horizon. This is due the changing needs of supplier's own businesses and the supplier's own policy on quality, lead time, prices over the time. Thus, it becomes necessary to take into account such information of all suppliers before selecting the supplier for any part in every period. Also, in TSSP it is assumed that the top ranked supplier is capable to supply all parts keeping same quality norms and within the lead time. This assumption makes the TSSP limited and unpractical as far as today's business is concerned. In order to handle such dynamic situation, organization needs to develop an analytical model capable of capturing complete information of all suppliers for each period. Analytical and qualitative models developed so far are very much capable to select the best supplier in the case of single period but cannot guarantee the selected supplier to be the best supplier for the case of multi-period. As a result, supplier for one period may not be the best supplier for the next period for supplying the same part type. Hence, the need to develop a multi-objective analytical model which can provide the optimal set of suppliers for all part types in each period increasing among business organizations. The supplier selection process in the case of multiple periods entirely different from the single period case as it involves more complexity in terms of selecting the suppliers for all periods minimizing the total supplier selection cost in the shortest lead time and meeting the desired quality level for each product set by an organization. In this paper, an attempt has been made to develop a mixed-integer non-linear formulation for the DSSP.

3. Problem definition

The problem considered here pertains to a dynamic environment of a business organization where the organization has to optimize the total cost of procuring multiple parts from multiple suppliers in multiple periods. There are suppliers supplying parts with different unit price, total transportation cost, varying quality parameters and lead time. From the past evidences, organization as a buyer has historical data of each supplier such as the amount of the extra time each supplier took to deliver the parts beyond the committed lead time. Similarly, each supplier has shown different quality level for different parts. Organization has to bear the cost for late arrival of the part and poor level of quality part due to delay in the manufacturing of finished goods product. In addition, supplier's capacity also differs from time to time due to their own internal or external issues. Organizations' demand for each product also varies in different period due to fluctuating market trends. In the following section, a MINLP is proposed to select the right supplier for the right part for a given planning horizon to optimize the total cost of selecting the suppliers. The total cost consider various cost parameters such as unit price of purchasing the part from supplier, cost for any delay beyond the lead time, cost of rejecting the parts due to poor quality level and fixed cost of transportation of parts from supplier. The proposed MINLP model incorporates risk associated with fluctuating demand, supply disruption, quality failure probability and delivery delay.

4. Mathematical model for dynamic supplier selection problem

In this section, MINLP model for multi-objective DSSP that relates the unit product cost for each supplier and product, fixed transportation cost of each supplier, quality level of each supplier for all product type and delay time beyond specified delivery time subject to constraints imposed by supplier's capacity for all period, period wise demand requirement generated at organization end, and quality parameter set by an organization for all product type. The proposed model's total costs can be expressed as follows:

Total Cost for entire period (T) = Cost of all products for period (T) + Fixed transportation cost for all Suppliers + Delay cost due to late delivery of the product from any supplier + penalty cost due to poor delivery of products

The development of the MINLP for multi-period, muti-source and multi-products integrating quality and lead time is based on the following notations:

T	Set of time period; 1,2,…,t
S	Set of suppliers; 1,2,…,s
P	Set of product type; 1,2,…,p
X_{tsp}	Number of product j supplied by supplier s for time period t
UC_{tsp}	Unit cost of product j for supplier s for time period t
TC_{ts}	Total transportation cost for product (irrespective of product type) by supplier s for time period t
Y_{ts}	Supplier assignment constant for time period t
SC_{tsp}	Capacity of supplier s for product p for time period t
D_{tp}	Demand for product p for time period t
UPC_{tsp}	Unit penalty cost to supplier s for product p for time period t
UDC_{tsp}	Unit delay cost to supplier s for product p for time period t
DLT_{tsp}	Delay lead time of supplier s for product p for time period t
Q_{tsp}	Quality level in period t of supplier s of part p
Q_o	Quality level set by organization

Minimize

$$\sum_{t=1}^{T}\sum_{s=1}^{S}\sum_{p=1}^{P}X_{tsp}UC_{sp}+\sum_{t=1}^{T}\sum_{s=1}^{S}TC_{ts}Y_{ts}+\sum_{t=1}^{T}\sum_{s=1}^{S}\sum_{p=1}^{P}(1-Q_{tsp})UPC_{tsp}X_{tsp}Y_{ts}+\sum_{t=1}^{T}\sum_{s=1}^{S}\sum_{p=1}^{P}UDC_{tsp}DLT_{tsp}X_{tsp}Y_{ts} \quad (1)$$

Subject to,

$$X_{tsp} \le SC_{tsp} \quad \forall t \in T,\ \forall s \in S,\ \forall p \in P \quad (2)$$

$$\sum_{s=1}^{s}X_{tsp} \leqslant D_{tp} \quad \forall t \in T,\ \forall p \in P \quad (3)$$

$$\sum_{s=1}^{s}X_{tsp}Y_{ts} = D_{tp} \quad \forall t \in T,\ \forall p \in P \quad (4)$$

$$Q_{tsp} \geqslant Q_o \quad \forall t \in T,\ \forall s \in S,\ \forall p \in P \quad (5)$$

$$Y_s = \begin{cases} 1 & \text{for } X_{tsp} > 0 \\ 0 & \end{cases} \quad \forall s \in S \quad (6)$$

$$X_{tsp} \geqslant 0 \quad \forall t \in T,\ \forall s \in S,\ \forall p \in P \quad (7)$$

The formulation involves minimizing the total cost (Eq. (1)) which is raised due to cost of all parts for entire period, fixed transportation cost for all suppliers, delay cost due to late delivery of the product from any supplier and penalty cost due to poor delivery of products. Eq. (2) represents the capacity constraint of all suppliers for all parts. Eq. (3) ensures that the organization's demand for all parts is satisfied by all suppliers combine. Constraint shown in Eq. (4) called as supplier's assignment constraint, ensures the binary restriction on supplier selected at any period. If the supplier "s" is selected to supply part "p" for period "t" then Y_{ts} will be 1 else 0. Eq. (5) enforces the selection of only those suppliers supplying the minimum quality level parts as set by the organization. Constraint set given in Eq. (6) enforces the binary nature on Y_{ts} while constraint in Eq. (7) enforces the non-negativity restriction on decision variables X_{tsp}.

5. Illustrative example

The MINLP for the dynamic supplier selection developed in the preceding section will now be illustrated by two numerical examples. Data for both the numerical examples have been generated randomly. In an illustrative example, case of a large firm engaged in manufacturing two different finished inventories as final products which is then directly sent to the market for sale. Both these products require some smaller parts which are being supplied from a pool of suppliers for each final product. Firm's demand for each part changes over the time due to market fluctuation and customer demand pattern of their final products. Based on the past experience firm know the demand of each part in a given planning horizon. In addition, supplier's capacity also changes due to its own

Table 1
Randomly generated data for the first period (2T-4S-3P problem).

T_1	P_1	P_2	P_3	TC
S_1	600, 30, 0.92, 4, 2, 10[a]	1000, 15, 0.95, 3, 0, 12	2000, 30, 0.90, 5, 3, 15	600
S_2	1000, 35, 0.88, 4, 1, 10	700, 14, 0.87, 3, 1, 12	1500, 22, 0.94, 5, 0, 15	750
S_3	800, 32, 0.93, 4, 4, 10	800, 20, 0.86, 3, 1, 12	2000, 25, 0.92, 5, 2, 15	650
S_4	800, 35, 0.93, 4, 3, 10	800, 22, 0.90, 3, 2, 12	2500, 30, 0.88, 5, 0, 15	650
Demand	1000	1600	2200	

[a] $\{SC_{tsp}, UC_{sp}, Q_{tsp}, UPC_{tsp}, DLT_{tsp}, UDC_{tsp}\}$.

Table 2
Randomly generated data for the second period (2T-4S-2P problem).

T_2	P_1	P_2	P_3	TC
S_1	1200, 40, 0.86, 5, 2, 13[a]	1800, 25, 0.89, 7, 0, 11	2200, 40, 0.87, 6, 3, 12	1000
S_2	2000, 45, 0.96, 5, 1, 13	1600, 24, 0.88, 7, 1, 11	1500, 32, 0.85, 6, 0, 12	1200
S_3	1400, 42, 0.92, 5, 4, 13	1200, 30, 0.92, 7, 1, 11	1500, 35, 0.92, 6, 2, 12	1500
S_4	1500, 45, 0.91, 5, 3, 13	2000, 32, 0.88, 7, 2, 11	1500, 40, 0.89, 6, 0, 12	1200
Demand	2500	3200	4500	

[a] $\{SC_{tsp}, UC_{sp}, Q_{tsp}, UPC_{tsp}, DLT_{tsp}, UDC_{tsp}\}$.

Table 3
Final result of supplier assignment and quantity supplied for the respective product (2T-4S-3P problem).

		S_1	S_2	S_3	S_4	D
T_1	P_1	0	1000	0	0	1000
	P_2	1000	600	0	0	1600
	P_3	0	1500	0	700	2200
	Y_i	1	1	0	1	
T_2	P_1	500	2000	0	0	2500
	P_2	1800	1400	0	0	3200
	P_3	0	1500	1500	1500	4500
	Y_i	1	1	1	1	

Objective function value = 584106.

commitment to other firm in its downstream and internal issues. All suppliers also know their own capacity to supply each product type in a given planning horizon. In addition to this, supplier's past performance in also available with the firm as far as their commitment to deliver the placed order within the due time and the quality level of each delivered product to the firm. In the illustrative Example 1 the case of four suppliers three products and two period (4S-3P-2T) is demonstrated. Similarly, in Example 2 a bigger case consisting of ten suppliers supplying seven different products in the planning horizon of four time period (10S-7P-4T) is numerically demonstrated. Following are the illustrated examples:

Example 1. In Example 1, we have taken the case of four suppliers, three parts and two periods (4S-3P-2T). The randomly generated data for supplier's capacity (SC_{tsp}), organization's demand for each part for both periods (D_{tp}), unit part cost for each suppliers (UC_{sp}), fixed transportation cost (TC_{ts}) of suppliers, quality level of all parts for each suppliers in each period (Q_{tsp}), unit penalty cost incurred by organization due to poor quality product (UPC_{tsp}), late delivery data of all suppliers for all parts (DLT_{tsp}) and unit delay cost

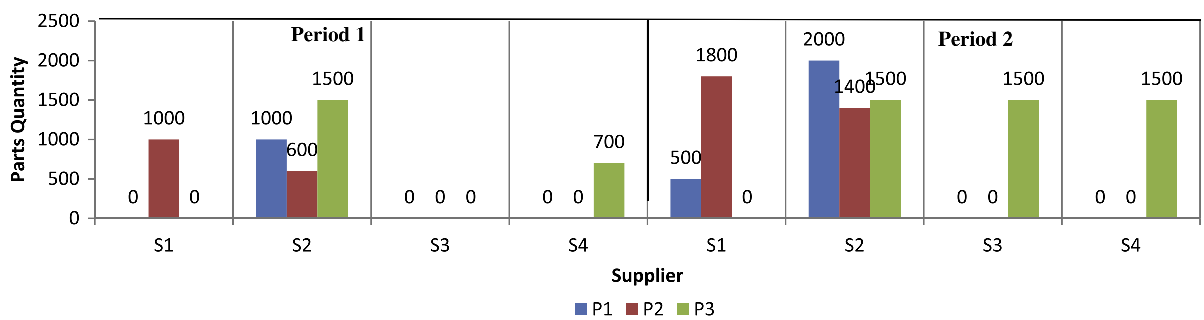

Fig. 1. Supplier-part distribution for period 1 and period 2 (S1, S2, S3, S4 refers to S_1, S_2, S_3, S_4; P1, P2, P3 refers to P_1, P_2, P_3).

Table 4
Randomly generated data for the first period (4T-10S-7P problem).

T_1	P_1	P_2	P_3	P_4	P_5	P_6	P_7	TC
S_1	300, 25, 0.85, 2, 2, 3[a]	100, 22, 0.9, 1.5, 1, 3	120, 18, 0.89, 1.5, 0, 5	500, 25, 0.92, 2.5, 0, 3.5	0, 23, 0.89, 2, 2, 3.5	300, 30, 0.92, 1.5, 3, 5	1000, 26, 0.92, 2, 0, 3.5	500
S_2	200, 25, 0.87, 2, 0, 3	200, 22, 0.87, 1.5, 0, 3	50, 18.5, 0.91, 1.5, 2, 5	220, 26, 0.9, 2.5, 3, 3.5	100, 25, 0.91, 2, 1, 3.5	300, 28, 0.96, 1.5, 2, 5	200, 26, 0.98, 2, 5, 3.5	500
S_3	200, 26.5, 0.95, 2, 3, 3	150, 22.5, 0.95, 1.5, 0, 3	160, 18.5, 0.95, 1.5, 0, 5	120, 25.5, 0.95, 2.5, 0, 3.5	100, 24, 0.95, 2, 0, 3.5	800, 28, 0.95, 1.5, 1, 5	100, 26, 0.95, 2, 2, 3.5	600
S_4	0, 24, 0.92, 2, 2, 3	100, 20, 0.94, 1.5, 2, 3	150, 18, 0.94, 1.5, 3, 5	150, 25, 0.92, 2.5, 4, 3.5	200, 25.5, 0.99, 2, 2, 3.5	500, 26.5, 0.98, 1.5, 1, 5	300, 26, 0.93, 2, 0, 3.5	550
S_5	400, 24, 0.96, 2, 0, 3	100, 20.5, 0.84, 1.5, 2, 3	200, 20, 0.92, 1.5, 3, 5	100, 26, 0.86, 2.5, 4, 3.5	350, 24, 0.95, 2, 5, 3.5	550, 25, 0.92, 1.5, 1, 5	50, 25.5, 0.92, 2, 2, 3.5	650
S_6	500, 25, 0.89, 2, 1, 3	50, 21, 0.97, 1.5, 1, 3	200, 20, 0.96, 1.5, 1, 5	300, 25.5, 0.98, 2.5, 2, 3.5	1000, 26, 0.97, 2, 0, 3.5	500, 25.5, 0.82, 1.5, 0, 5	60, 25.5, 0.8, 2, 0, 3.5	550
S_7	350, 25.5, 0.95, 2, 1, 3	0, 21.5, 0.89, 1.5, 2, 3	100, 19, 0.93, 1.5, 2, 5	100, 25.5, 0.91, 2.5, 3, 3.5	500, 26.5, 0.91, 2, 5, 3.5	120, 25, 0.91, 1.5, 4, 5	100, 26, 0.91, 2, 1, 3.5	700
S_8	250, 24, 0.92, 2, 1, 3	400, 21, 0.93, 1.5, 1, 3	0, 20, 0.94, 1.5, 1, 5	200, 25.5, 0.94, 2.5, 1, 3.5	500, 25.5, 0.98, 2, 1, 3.5	400, 30, 0.98, 1.5, 0, 5	150, 26.5, 0.87, 2, 0, 3.5	550
S_9	250, 24, 0.9, 2, 2, 3	300, 22.5, 0.92, 1.5, 2, 3	150, 18.5, 0.94, 1.5, 0, 5	500, 24, 0.93, 2.5, 2, 3.5	100, 25.5, 0.94, 2, 2, 3.5	600, 30, 0.87, 1.5, 1, 5	80, 25.5, 0.92, 2, 2, 3.5	700
S_{10}	300, 24, 0.9, 2, 3, 3	350, 23, 0.92, 1.5, 4, 3	140, 19, 0.92, 1.5, 4, 5	50, 24.5, 0.91, 2.5, 2, 3.5	400, 24, 0.91, 2, 0, 3.5	100, 29.5, 0.81, 1.5, 3, 5	20, 26, 0.8, 2, 4, 3.5	600
Demand	1000	1200	800	1600	1500	1700	1500	

[a] {SC_{tsp}, UC_{sp}, Q_{tsp}, UPC_{tsp}, DLT_{tsp}, UDC_{tsp}}:T_1.

Table 5
Randomly generated data for the second period (4T-10S-7P problem).

T_2	P_1	P_2	P_3	P_4	P_5	P_6	P_7	TC
S_1	100, 27, 0.85, 2, 2, 3.5[a]	80, 24, 0.9, 2.5, 1, 3	10, 20, 0.89, 1.5, 0, 4.5	200, 27, 0.92, 2.5, 0, 4	220, 25, 0.89, 3, 2, 4	100, 32, 0.92, 1.5, 3, 2	1000, 28, 0.92, 2.5, 0, 3	600
S_2	100, 27, 0.87, 2, 0, 3.5	150, 24, 0.87, 2.5, 0, 3	0, 20.5, 0.91, 1.5, 2, 4.5	250, 28, 0.9, 2.5, 3, 4	140, 27, 0.91, 3, 1, 4	120, 30, 0.96, 1.5, 2, 2	200, 28, 0.98, 2.5, 5, 3	600
S_3	100, 28.5, 0.95, 2, 3, 3.5	200, 24.5, 0.95, 2.5, 0, 3	80, 20.5, 0.95, 1.5, 0, 4.5	250, 27.5, 0.95, 2.5, 0, 4	120, 26, 0.95, 3, 0, 4	500, 30, 0.95, 1.5, 1, 2	800, 28, 0.95, 2.5, 2, 3	700
S_4	0, 26, 0.92, 2, 2, 3.5	0, 22, 0.94, 2.5, 2, 3	0, 20, 0.94, 1.5, 3, 4.5	0, 27, 0.92, 2.5, 4, 4	0, 27.5, 0.99, 3, 2, 4	0, 28.5, 0.98, 1.5, 1, 2	0, 28, 0.93, 2.5, 0, 3	650
S_5	50, 26, 0.96, 2, 0, 3.5	1000, 22.5, 0.84, 2.5, 2, 3	60, 22, 0.92, 1.5, 3, 4.5	150, 28, 0.86, 2.5, 4, 4	550, 26, 0.95, 3, 5, 4	600, 27, 0.92, 1.5, 1, 2	250, 27.5, 0.92, 2.5, 2, 3	750
S_6	150, 27, 0.89, 2, 1, 3.5	200, 23, 0.97, 2.5, 1, 3	100, 22, 0.96, 1.5, 1, 4.5	120, 27.5, 0.98, 2.5, 2, 4	600, 28, 0.97, 3, 0, 4	240, 27.5, 0.82, 1.5, 0, 2	200, 27.5, 0.8, 2.5, 0, 3	650
S_7	550, 27.5, 0.95, 2, 1, 3.5	250, 23.5, 0.89, 2.5, 2, 3	60, 21, 0.93, 1.5, 2, 4.5	140, 27.5, 0.91, 2.5, 3, 4	120, 28.5, 0.91, 3, 5, 4	120, 27, 0.91, 1.5, 4, 2	100, 28, 0.91, 2.5, 1, 3	800
S_8	240, 26, 0.92, 2, 1, 3.5	250, 23, 0.93, 2.5, 1, 3	150, 22, 0.94, 1.5, 1, 4.5	300, 27.5, 0.94, 2.5, 1, 4	200, 27.5, 0.98, 3, 1, 4	180, 32, 0.98, 1.5, 0, 2	120, 25.5, 0.87, 2.5, 0, 3	650
S_9	580, 26, 0.9, 2, 2, 3.5	250, 24.5, 0.92, 2.5, 2, 3	130, 20.5, 0.94, 1.5, 0, 4.5	500, 26, 0.93, 2.5, 2, 4	400, 27.5, 0.94, 3, 2, 4	0, 32, 0.87, 1.5, 1, 2	200, 27.5, 0.92, 2.5, 2, 3	800
S_{10}	600, 26, 0.9, 2, 3, 3.5	250, 25, 0.92, 2.5, 4, 3	120, 21, 0.92, 1.5, 4, 4.5	200, 26.5, 0.91, 2.5, 2, 4	100, 26, 0.91, 3, 0, 4	200, 31.5, 0.81, 1.5, 3, 2	50, 28, 0.8, 2.5, 4, 3	700
Demand	2000	2000	0	1800	1200	2000	2000	

[a] {SC_{tsp}, UC_{sp}, Q_{tsp}, UPC_{tsp}, DLT_{tsp}, UDC_{tsp}}: T_2.

Table 6
Randomly generated data for the third period (4T-10S-7P problem).

T_3	P_1	P_2	P_3	P_4	P_5	P_6	P_7	TC
S_1	100,27,0.8,3,2,3.5[a]	100,24,0.91,3.5,1,3	220,20,0.92,2.5,0,4.5	400,27,0.98,3.5,0,4	130,25,0.91,4,2,4	100,32,0.86,2.5,3,2	1000,28,0.95,3.5,0,3	800
S_2	100,27,0.85,3,0,3.5	100,24,0.89,3.5,0,3	220,20.5,0.91,2.5,2,4.5	800,28,0.97,3.5,3,4	120,27,0.97,4,1,4	1000,30,0.91,2.5,2,2	500,28,0.92,3.5,5,3	800
S_3	150,28.5,0.82,3,3,3.5	200,24.5,0.82,3.5,0,3	100,20.5,0.92,2.5,0,4.5	500,27.5,0.84,3.5,0,4	200,26,0.95,4,0,4	500,30,0.92,2.5,1,2	500,28,0.96,3.5,2,3	900
S_4	150,26,0.91,3,2,3.5	250,22,0.91,3.5,2,3	500,20,0.96,2.5,3,4.5	200,27,0.89,3.5,4,4	300,27.5,0.92,4,2,4	200,28.5,0.93,2.5,1,2	100,28,0.95,3.5,0,3	850
S_5	120,26,0.91,3,0,3.5	240,22.5,0.91,3.5,2,3	300,22,0.93,2.5,3,4.5	250,28,0.96,3.5,4,4	230,26,0.95,4,5,4	250,27,0.91,2.5,1,2	0,27.5,0.91,3.5,2,3	950
S_6	150,27,0.93,3,1,3.5	100,23,0.91,3.5,1,3	400,22,0.92,2.5,1,4.5	100,27.5,0.91,3.5,2,4	400,28,0.96,4,0,4	250,27.5,0.92,2.5,0,2	300,27.5,0.92,3.5,0,3	850
S_7	100,27.5,0.98,3,1,3.5	500,23.5,0.95,3.5,2,3	800,21,0.97,2.5,2,4.5	250,27.5,0.89,3.5,3,4	1000,28.5,0.91,4,5,4	750,27,0.96,2.5,4,2	400,28,0.95,3.5,1,3	1000
S_8	0,26,0.95,3,1,3.5	0,23,0.96,3.5,1,3	0,22,0.95,2.5,1,4.5	0,27.5,0.92,3.5,1,4	0,27.5,0.97,4,1,4	0,32,0.97,2.5,0,2	0,25.5,0.97,3.5,0,3	850
S_9	200,26,0.92,3,2,3.5	150,24.5,0.96,3.5,2,3	100,20.5,0.95,2.5,0,4.5	200,26,0.92,3.5,2,4	500,27.5,0.98,4,2,4	200,32,0.92,2.5,1,2	500,27.5,0.91,3.5,2,3	1000
S_{10}	250,26,0.91,3,3,3.5	250,25,0.94,3.5,4,3	400,21,0.92,2.5,4,4.5	800,26.5,0.91,3.5,2,4	100,26,0.95,4,0,4	450,31.5,0.97,2.5,3,2	100,28,0.98,3.5,4,3	900
Demand	0	0	1800	1200	1500	1800	2000	

[a] {SC_{tsp}, UC_{sp}, Q_{tsp}, UPC_{tsp}, DLT_{tsp}, UDC_{tsp}}: T_3.

Table 7
Randomly generated data for the fourth period (4T-10S-7P problem).

T_4	P_1	P_2	P_3	P_4	P_5	P_6	P_7	TC
S_1	1200,32,0.8,3,2,4.5[a]	120,29,0.91,3.5,1,4	250,25,0.92,2.5,0,5.5	400,32,0.98,3.5,0,5	1000,30,0.91,4,2,5	800,37,0.86,2.5,3,3	1000,33,0.95,3.5,0,4	1300
S_2	130,32,0.85,3,0,4.5	120,29,0.89,3.5,0,4	200,25.5,0.91,2.5,2,5.5	500,33,0.97,3.5,3,5	800,32,0.97,4,1,5	800,35,0.91,2.5,2,3	0,33,0.92,3.5,5,4	1300
S_3	100,33.5,0.82,3,3,4.5	300,29.5,0.82,3.5,0,4	200,25.5,0.92,2.5,0,5.5	80,32.5,0.84,3.5,0,5	300,31,0.95,4,0,5	400,35,0.92,2.5,1,3	300,33,0.96,3.5,2,4	1400
S_4	500,31,0.91,3,2,4.5	400,27,0.91,3.5,2,4	200,25,0.96,2.5,3,5.5	200,32,0.89,3.5,4,5	1200,32.5,0.92,4,2,5	1400,33.5,0.93,2.5,1,3	800,33,0.95,3.5,0,4	1350
S_5	550,31,0.91,3,0,4.5	400,27.5,0.91,3.5,2,4	1800,27,0.93,2.5,3,5.5	1200,33,0.96,3.5,4,5	750,31,0.95,4,5,5	500,32,0.91,2.5,1,3	500,32.5,0.91,3.5,2,4	1450
S_6	100,32,0.93,3,1,4.5	200,28,0.91,3.5,1,4	250,27,0.92,2.5,1,5.5	150,32.5,0.91,3.5,2,5	300,33,0.96,4,0,5	150,32.5,0.92,2.5,0,3	200,32.5,0.92,3.5,0,4	1350
S_7	150,32.5,0.98,3,1,4.5	120,28.5,0.95,3.5,2,4	450,26,0.97,2.5,2,5.5	400,32.5,0.89,3.5,3,5	600,33.5,0.91,4,5,5	500,32,0.96,2.5,4,3	200,33,0.95,3.5,1,4	1500
S_8	800,31,0.95,3,1,4.5	1500,28,0.96,3.5,1,4	1200,27,0.95,2.5,1,5.5	0,32.5,0.92,3.5,1,5	800,32.5,0.97,4,1,5	300,37,0.97,2.5,0,3	400,30.5,0.97,3.5,0,4	1350
S_9	120,31,0.92,3,2,4.5	130,29.5,0.96,3.5,2,4	200,25.5,0.95,2.5,0,5.5	150,31,0.92,3.5,2,5	240,32.5,0.98,4,2,5	300,37,0.92,2.5,1,3	200,32.5,0.91,3.5,2,4	1500
S_{10}	600,31,0.91,3,3,4.5	200,30,0.94,3.5,4,4	0,26,0.92,2.5,4,5.5	1100,31.5,0.91,3.5,2,5	850,31,0.95,4,0,5	1000,36.5,0.97,2.5,3,3	1200,33,0.98,3.5,4,4	1400
Demand	1500	0	0	1600	2000	1400	0	

[a] {SC_{tsp}, UC_{sp}, Q_{tsp}, UPC_{tsp}, DLT_{tsp}, UDC_{tsp}}:T_4.

Table 8
Final result of supplier assignment and quantity supplied for the respective product (4T-10S-7P problem).

		S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	D
T_1	P_1	0	200	0	0	400	150	0	250	0	0	100
	P_2	100	200	150	100	100	50	0	400	100	0	1200
	P_3	120	50	160	20	0	200	100	0	150	0	800
	P_4	500	0	120	0	0	230	0	200	500	50	1600
	P_5	0	0	100	0	0	1000	0	0	0	400	1500
	P_6	0	0	0	250	550	500	0	400	0	0	1700
	P_7	1000	0	0	300	0	60	0	140	0	0	1500
	Y_i	1	1	1	1	1	1	1	1	1	1	
T_2	P_1	100	100	0	0	50	150	550	240	580	230	2000
	P_2	80	150	200	0	1000	200	120	360	0	0	2000
	P_3	0	0	0	0	0	0	0	0	0	0	0
	P_4	200	90	250	0	0	120	140	300	500	200	1800
	P_5	40	140	120	0	0	600	0	200	0	100	1200
	P_6	40	120	500	0	600	240	120	180	0	200	2000
	P_7	1000	0	130	0	250	200	100	120	200	0	2000
	$\mathbf{Y_i}$	1	1	1	0	1	1	1	1	1	1	
$\mathbf{T_3}$	P_1	0	0	0	0	0	0	0	0	0	0	0
	P_2	0	0	0	0	0	0	0	0	0	0	0
	P_3	220	220	0	60	0	400	800	0	100	0	1800
	P_4	400	0	0	0	0	0	0	0	200	600	1200
	P_5	130	120	0	250	0	400	0	0	500	100	1500
	P_6	0	900	0	200	250	250	0	0	200	0	1800
	P_7	1000	0	0	100	0	300	400	0	200	0	2000
	Y_i	1	1	0	1	1	1	1	0	1	1	
T_4	P_1	0	130	0	0	550	20	0	800	0	0	1500
	$\mathbf{P_2}$	0	0	0	0	0	0	0	0	0	0	0
	P_3	0	0	0	0	0	0	0	0	0	0	0
	P_4	400	0	80	0	0	0	0	0	150	970	1600
	P_5	0	550	300	0	0	300	0	0	0	850	200
	$\mathbf{P_6}$	0	0	0	750	500	150	0	0	0	0	1400
	P_7	0	0	0	0	0	0	0	0	0	0	0
	Y_i	1	1	1	1	1	1	0	1	1	1	

Objective function value = 1107808.

incurred by an organization due to late arrival of parts from all suppliers (UDC_{tsp}). All randomly generated data are tabulated in Tables 1 and 2 for period 1 and period 2 respectively. The randomly generated data provided in tables follow {SC_{tsp}, UC_{sp}, Q_{tsp}, UPC_{tsp}, DLT_{tsp}, UDC_{tsp}} sequence.

The proposed model MINLP is programmed in LINGO and using randomly generated data shown in Tables 1 and 2, the MINLP is solved. Results obtained are shown in Table 3 with the overall objective function value. The supplier part distribution for both periods is shown in Fig. 1.

Result in Table 3 shows that the organization selects three suppliers i.e. S_1, S_2 and S_4 for T_1 and four suppliers i.e. S_1, S_2, S_3 and S_4 for T_2.

For the period T_1: S_1 supply $P_2 = 1000$; S_2 supply $P_1 = 1000$, $P_2 = 600$ and $P_3 = 1500$.

For the period T_2: S_1 supply $P_1 = 500$ and $P_2 = 1800$; S_2 supply $P_1 = 2000$, $P_2 = 1400$ and $P_3 = 1500$; S_3 supply only $P_3 = 1500$. The objective function value for the supplier selection model is 584106

Example 2. In Example 2, we analysed bigger problem for the case of ten suppliers, seven parts and four periods (10S-7P-4T). Data has been generated randomly. Tables 4–7 represents data for period T_1 to T_4, respectively. The randomly generated data provided in tables follow {SC_{tsp}, UC_{sp}, Q_{tsp}, UPC_{tsp}, DLT_{tsp}, UDC_{tsp}}: sequence.

Results obtained from LINGO is summarized in Table 8. Table 8 shows that the organization would select all suppliers i.e. S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10} for T_1; nine suppliers i.e. S_1, S_2, S_3, S_5, S_6, S_7, S_8, S_9, S_{10} for T_2; eight suppliers i.e. S_1, S_2, S_4, S_5, S_6, S_7, S_9, S_{10} for T_3; and nine suppliers i.e. S_1, S_2, S_3, S_4, S_5, S_6, S_8, S_9, S_{10} for T_4. This can be also seen from the supplier part distribution for period 1, period 2, period 3 and period 4 shown in Figs. 2–5 respectively. The objective function value for the supplier selection model is 1107808.

For the period T_1: $\mathbf{S_1}$ supply $P_2 = 100$, $P_3 = 120$, $P_4 = 500$ and $P_7 = 1000$; $\mathbf{S_2}$ supply $P_1 = 200$, $P_2 = 200$ and $P_3 = 50$; $\mathbf{S_3}$ supply $P_2 = 150$, $P_3 = 160$, $P_4 = 120$ and $P_5 = 100$; $\mathbf{S_4}$ supply $P_2 = 100$, $P_3 = 20$, $P_6 = 250$ and $P_7 = 300$; $\mathbf{S_5}$ supply $P_1 = 400$, $P_2 = 100$ and $P_6 = 550$; $\mathbf{S_6}$ supply $P_1 = 150$, $P_2 = 50$, $P_3 = 200$, $P_4 = 230$, $P_5 = 1000$,

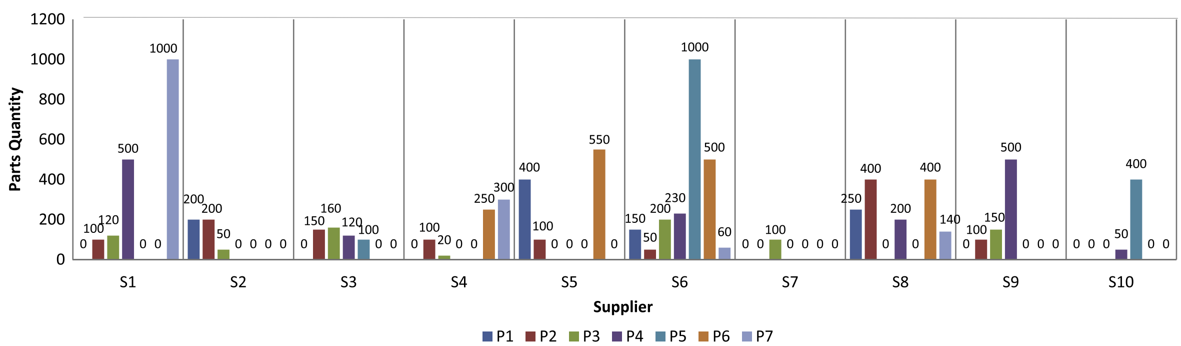

Fig. 2. Supplier-part distribution for the period T_1 (S1, S2, S3, S4, S5, S6, S7, S8, S9, S10 refers to S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10} P2, P3, P4, P5, P6, P7 refers to P_1, P_2, P_3, P_4, P_5, P_6, P_7).

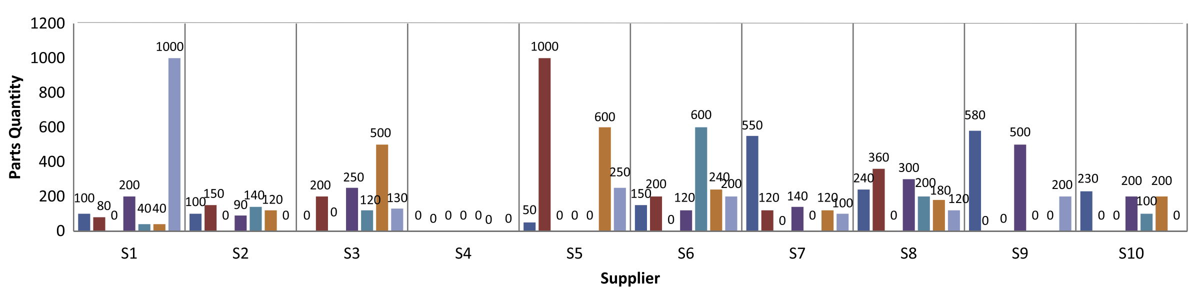

Fig. 3. Supplier-part distribution for the period T_2.

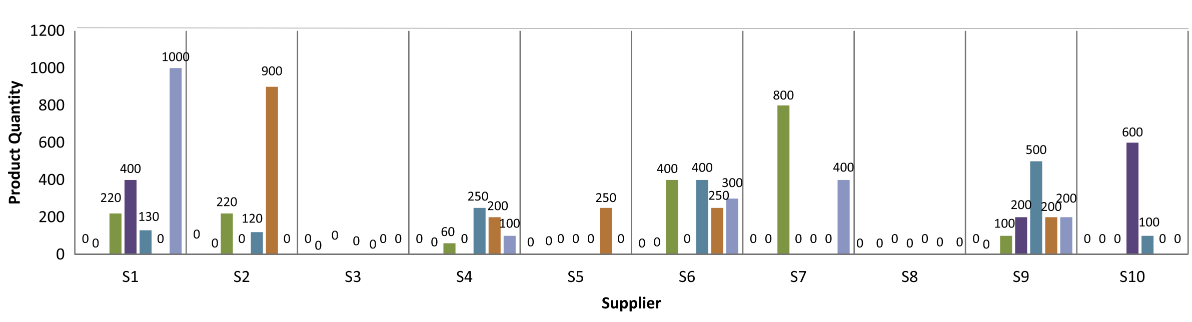

Fig. 4. Supplier-part distribution for the period T_3.

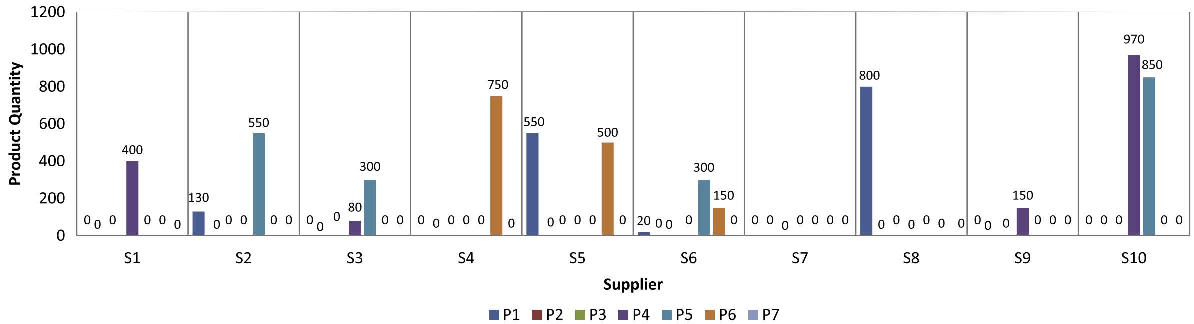

Fig. 5. Supplier-part distribution for the period T_4.

$P_6 = 500$, $P_7 = 60$; $\mathbf{S_7}$ supply $P_3 = 100$; $\mathbf{S_8}$ supply $P_1 = 250$, $P_2 = 400$, $P_4 = 200$, $P_6 = 400$, $P_7 = 140$; $\mathbf{S_9}$ supply $P_2 = 100$, $P_3 = 150$ and $P_4 = 500$; and $\mathbf{S_{10}}$ supply $P_4 = 50$ and $P_5 = 400$.

For the period T_2: $\mathbf{S_1}$ supply $P_1 = 100$, $P_2 = 80$, $P_4 = 200$, $P_5 = 40$, $P_6 = 40$ and $P_7 = 1000$; $\mathbf{S_2}$ supply $P_1 = 100$, $P_2 = 150$, $P_4 = 90$, $P_5 = 140$ and $P_6 = 120$; $\mathbf{S_3}$ supply $P_2 = 200$, $P_4 = 250$, $P_5 = 120$, $P_6 = 500$ and $P_7 = 130$; $\mathbf{S_4}$ do not supply any parts; $\mathbf{S_5}$ supply $P_1 = 50$, $P_2 = 1000$, $P_6 = 600$ and $P_7 = 250$; $\mathbf{S_6}$ supply $P_1 = 150$, $P_2 = 200$, $P_4 = 120$, $P_5 = 600$, $P_6 = 240$ and $P_7 = 200$; $\mathbf{S_7}$ supply $P_1 = 550$, $P_2 = 120$, $P_4 = 140$, $P_6 = 120$ and $P_7 = 100$; $\mathbf{S_8}$ supply $P_1 = 240$, $P_2 = 360$, $P_4 = 300$, $P_5 = 200$, $P_6 = 180$ and $P_7 = 120$; $\mathbf{S_9}$ supply $P_1 = 580$, $P_4 = 500$ and $P_7 = 200$; and $\mathbf{S_{10}}$ supply $P_1 = 230$, $P_4 = 200$, $P_5 = 100$ and $P_6 = 200$.

For the period T_3: $\mathbf{S_1}$ supply $P_3 = 220$, $P_4 = 400$, $P_5 = 130$ and $P_7 = 1000$; $\mathbf{S_2}$ supply $P_3 = 220$, $P_5 = 120$ and $P_6 = 900$; $\mathbf{S_3}$ do not supply any parts; $\mathbf{S_4}$ supply $P_3 = 60$, $P_5 = 250$, $P_6 = 200$ and $P_7 = 100$; $\mathbf{S_5}$ supply $P_6 = 250$; $\mathbf{S_6}$ supply $P_3 = 400$, $P_5 = 400$, $P_6 = 250$ and $P_7 = 300$; $\mathbf{S_7}$ supply $P_3 = 800$, and $P_7 = 400$; $\mathbf{S_8}$ do not supply any parts; $\mathbf{S_9}$ supply $P_3 = 100$, $P_4 = 200$, $P_5 = 500$, $P_6 = 200$ and $P_7 = 200$; and $\mathbf{S_{10}}$ supply $P_4 = 600$ and $P_5 = 100$.

For the period T_4: $\mathbf{S_1}$ supply $P_4 = 400$; $\mathbf{S_2}$ supply $P_1 = 130$ and $P_5 = 550$; $\mathbf{S_3}$ supply $P_4 = 80$, and $P_5 = 300$; $\mathbf{S_4}$ supply $P_6 = 750$; $\mathbf{S_5}$ supply $P_1 = 550$ and $P_6 = 550$; $\mathbf{S_6}$ supply $P_1 = 20$, $P_5 = 300$, $P_6 = 150$, $P_7 = 0$; $\mathbf{S_7}$ do not supply any parts; $\mathbf{S_8}$ supply $P_1 = 800$; $\mathbf{S_9}$ supply $P_4 = 150$; and $\mathbf{S_{10}}$ supply $P_4 = 970$ and $P_5 = 850$.

6. Conclusion and scope for future work

In this paper, supplier selection problem is described for multi-period case. The problem has been mathematically modeled as a MINLP. To validate the proposed model, random data are generated and tested on LINGO optimization software. To demonstrate the model, a numerical illustration is also provided for two different cases i.e. 2T-4S-3P and 4T-10S-7P. In the present work uncertainty is not incorporated in the model. Therefore, incorporating uncertainties in the form of parts demand from market, capacity of supplier and various echelons in the supply chain, uncertainty in supplier lead time, quality uncertainty, and production failure can be taken as future research direction. In addition, qualitative and quantitative environmental and liability issues can be also taken care in the future research. The proposed MINLP model can be applicable in the real situation in the form of case studies. Random data generated in this paper can be also replaced by real time data.

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