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Research Article

MULTI-CRITERIA SUPPLIER SELECTION AND PURCHASE PROBLEM

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ABSTRACT

In this paper, multi-criteria supplier selection and purchase problem (*MCSSPP*) is introduced and a solution approach for *MCSSPP* is proposed. *MCSSPP* is about purchasing of the raw materials from the best suppliers allowed for the amount of the defect between echelons for a single-product multi-echelon supply chain network (*SMSCN*). For *MCSSPP,* the quality, price and distance criteria which had different units were considered. As it is not possible to use different criteria with different units in mathematical model, an alternative mathematical model Ng was used in this study for the solution approach. In the solution approach, first, the best supplier was determined and then *SMSCN* was optimized with *LINDO* program by using the mixed-integer linear programming model to minimise the total costs. Total costs comprised of the transportation cost of raw material *s* from supplier *i* to factory, the purchasing cost of raw material *s* from supplier *i*, the unit transportation cost of product from factory to distribution centre *m* and unit transportation cost of product from distribution centre *m* to customer *n*, the fixed operating cost of factory, the fixed operating cost of distribution centre *m*, and the production cost. *MCSSPP* and the proposed solution approach were applied to a chair product of enterprise *XYZ* in Kayseri, Turkey. The chair product had four raw materials, and each raw material had two suppliers. The mathematical results were compared for the best and the worst models. From *8* different suppliers, the total cost of the best model was obtained as *553926. 6* TLs with *17328* units carcass groups, 17146 units seat groups, 17328 units sponges and 17328 units packages. However, for the worst model, the total cost was *562834.9* TLs with *16964* units carcass groups, *16964* units seat groups, *17143* units sponges and *17143* units packages purchased. In conclusion, by utilizing the proposed mathematical model, the total cost was reduced %1.61 (*8908.3* TLs).
Keywords: Supply chain management, single-product multi-echelon supply chain network design, optimization, multi-criteria supplier selection and purchase problem.

1. INTRODUCTION

Due to today's challenging and competitive business environment, reducing costs has become crucial and a lot of effort should be taken by firms. For example, they can choose the best supplier(s) to realize this goal. As the supply chain is an interconnected system requiring in cooperation of collaborators, the selection of collaborators plays an important role in supply chain management (*SCM*) [1]. Selecting the appropriate collaborators can effectively reduce the major cost for a product which consists of two basic components: raw material cost and raw material parts and strengthens the business competitiveness. In particular, most firms consume

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considerable amount of their incomes on purchasing. For these reasons, the supplier selection process (*SSP*) has gained attention [2].

However, selecting the supplier that proposes the lowest price is not enough and multi-criteria need to be focused when choosing suppliers. In the literature, there are many different criteria in the multi-criteria supplier selection [3-11].

In this paper, we consider the case where purchasing product raw materials from the best suppliers, at the most competitive prices, producing in the most suitable quantities, storing the produced items in the most appropriate quantities and delivering the products to the customers from distribution centres (*DCs*) according to the size of the defect between echelons under deterministic conditions [5-8]. There are two phases in the solution of the proposed problem. In the first phase, the best supplier according to the Ng model (supplier selection phase) is selected. After this phase, the total cost of single-product multi-echelon supply chain network of the enterprise XYZ (system cost optimization phase) are minimized. The problem is solved in two phases because the units of criteria are different. For that reason, we cannot use these criteria together in system cost optimization phase.

The chairmodel-1 as single product is investigated. The chairmodel-1 has four raw materials. These are in carcass groups (*S1*); seat groups (*S2*), sponges (*S3*) and packages (*S4*). We assume that each of the raw materials has two suppliers. We focus on three different criteria (quality, price and distance) for supplier selection phase in this study. These criteria are already being used by the enterprise. For this reason, we used these criteria in the application. The quality of the purchased parts is also a critical criterion for an enterprise in supplier selection. The distance is about delivery efficiency. The ‘‘delivery’’ criterion measures the percentage of on time deliveries. Finally, the price denotes the calculated price level offered by a supplier as compared to the average market price [3]. When the suppliers are selected then the total cost of single-product multi-echelon supply chain network of the enterprise XYZ with the mixed integer linear programming (*MILP)is optimised* by using *LINDO* software. Finally, the amount of purchased raw materials from related suppliers and the suppliers which we collaborate for each raw material is determined by the getting solution of multi-criteria supplier selection purchase problem.

The difference of this study from studies in the literature is selecting suppliers according to the multi-criteria with the optimization of supply chain network. The significant contribution of this study is that it proposes a new type supplier selection and purchase problem and the solution of this new problem with an application.

SCM and *SSP* have large-scale consideration in the literature and the methods to address the supplier selection problem have grouped into three types of models as mathematical programming, cost-based, and categorical [2]. There are also studies with genetic algorithms; artificial intelligence techniques, etc. (see references [10, 12]) for *SCM* and *SSP*.

The literature about this study can be divided into two parts: the defective supply chain system (*DSCS*) and the supplier selection and purchase problem (*SSPP*). In *DSCS*, unequal input and output may occur; therefore, the case should be taken into account to make the production system more realistic. Early studies discussed reject allowances, which are extra inputs required to fulfil the order. Much of the literature concerning different yield rate systems has covered only the single-order system [4, 5]. A supply chain which has defects with at least one echelon is called the multi-echelon defective supply chain (*MDSC*) system [5-8].

Burke *et al.* analysed single period, single product sourcing decisions under demand uncertainty [6, 13].

Awasthi *et al.* studied a supplier selection problem for a single manufacturer/retailer that faces a random demand with a limitation on minimum and maximum order sizes [6, 14].

Zhang and Zhang [6, 15] studied supplier selection and purchase problem considering minimal ordering quantity and suppliers’ limitation on capacity under stochastic demand. Our study focuses on multi criteria supplier selection while Zhang and Zhang’s study is focus on stochastic demands.

Senyigit and Golec proposed a new heuristic for *SSPP* for *MDSC* systems with stochastic demand. They investigated the performance of the proposed *H1* heuristic using *4* cases. They assumed that supplier s' capacities are infinite. Their paper was the first study about *SSPP* for *MDSC* system with stochastic demand in the literature [5].

Senyigit studied the purchasing costs of raw materials, production costs, fixed operation costs, transportation costs and lost sales costs in his study similar to his earlier study with Golec. *ProModel* simulation software was used to model the heuristics and *MDSCN* system. Senyigit extended the work he did with Golec with finite supplier capacity and a new heuristic. Additionally, a real case study using of these heuristics in the Turkish furniture firm was presented [6].

Senyigit and Soylemez focused on the multi-echelon multi-product defective supply chain network (*MMDSCN*) of firm *X* in Kayseri, Turkey which produces chairs under uncertain demand. This manuscript was a proceeding paper. Our aim is to differentiate Senyigit and Soylemez's proceeding paper with a new perspective. They assumed that the demands of customers were stochastic and normally distributed. They noted that *Benny1* and *Maksim* chairs as products. They proposed two heuristics for the solution of this problem. They formed an *MMDSCN* system of firm *X* with the mixed integer linear programming (*MILP)* by using *LINDO*. The heuristics and *MMDSCN* system were modelled by ARENA 4.0. Simulation experiments showed that the proposed *H2* heuristic outperformed the *H1* heuristic [7].

Senyigit proposed a new problem called the lot-sizing with supplier selection problem (*LSSP*) in the *MDSCN*. He showed the multi-product *MDSCN* of enterprise *X* [8].

Ho *et al.* investigated 78 different studies about supplier selection and evaluation. One of the results of their studies was to establish the three most commonly used criteria are quality, price and lead time [9].

Alfares and Turnadi show a realistic multi-item lot-sizing problem with multiple suppliers, multiple time periods, quantity discounts, and backordering of shortages by using MILP [10].

Hamdi *et al.* review the literature in the field of supplier selection under supply chain risk management [12].

The rest of the paper is as follows. Section 1 of the study presents introduction and earlier studies on multi-criteria supplier selection and purchase problems. Section 2 gives information about proposed mathematical models for the problem (Ng Model, Mixed integer linear programming, *etc*.) and application. Section 3 presents the results of the study. The last section gives information about the concluding remarks and future studies.

2. METHODS

In this section, the notation is described to be used in this model, firstly. Ng model are presented for multi-criteria supplier selection. Finally, the mathematical model of the *SMSCN* system which we differentiated our earlier study is proposed by using multi-criteria in supplier selection process. The notations used in the model and their meanings are listed as below [7]:

Indices/Sets:

I Suppliers.
S Raw materials.
M Distributions Centres (DC)
N Customers.
J Criteria.

Parameters:

P The production capacity limits on the factory.
$\mathbf{K_m}$ The capacity limits of the distribution centre *m*.
$\mathbf{K_{si}}$ The capacity limits on raw material *s* of supplier *i*
$\mathbf{D_n}$ The total demand of customer n.

C_{si} The transportation cost of raw material *s* from supplier *i* to factory.
SC_{si} The purchasing cost of raw material s from supplier *i* to factory.
C_m Unit transportation cost of product from factory *to* distribution centre *m*.
C_{mn} Unit transportation cost of product from distribution centre *m* to customer *n*.
F The fixed operating cost of factory.
F_m The fixed operating cost of distribution centre *m*.
ω_s Units of raw material *s* required to produce one unit of product according to the product bill of material.
U The average defect rate of factory.
V_m The average defect rate of distribution centre *m*.
T_{si} The average defect rate of supplier *i* for raw material *s*.
PC The production cost.
TC Total cost.

Decision Variables:
X_{si} The total units of raw material *s* purchased from supplier *i*
Y_m The amount of product from factory to distribution centre *m*.
Z_{mn} Total units of product distributed from *DC m* to customer zone *n*.

X_{ij} The score of j^{th} criteria of supplier *i*.
W_{ij} The weight of criteria *j* of supplier *i*.
Y_{ij} Transformed measures of criteria *j* of supplier *i*.
S_{si} The score of supplier *i* for raw material *s*.

Binary Variable:

$$\propto_{si}=\begin{cases} 1, & if \quad supplier\ i\ for\ component\ s\ for\ product\ is\ used \\ 0, & if \quad supplier\ i\ for\ component\ s\ for\ product\ is\ not\ used \end{cases}$$

$$\beta_{si}=\begin{cases} 1, & if \quad supplier\ i\ is\ selected\ by\ Ng\ model \\ 0, & if \quad supplier\ i\ is\ not\ selected\ by\ Ng\ model \end{cases}$$

2.1. NG MODEL

The *MCSSPP* are in a *SMSCN* based on two parts. First, the best supplier for each raw material is determined. Ng model is for the multi-criteria supplier selection. W_{ij} represents the weight of criteria *j* of supplier *i*. Y_{ij} is transformed measures of criteria *j* of supplier *i*. Second, the *SMSCN* of enterprise *XYZ* are optimised by *MILP*. The total cost of the system is obtained from the optimization solution. The best supplier for each raw material and the optimum purchasing quantities from these best suppliers are determined.

Ng model can be given below [3]:

$$Max \quad S_{si}=\sum_{j=1}^{J} W_{ij} * Y_{ij} \tag{1}$$

s.t.

$$W_{ij} - W_{i(j+1)} \geq 0 \qquad j=1,2,...,(J-1) \tag{2}$$

$$\sum_{j=1}^{J} W_{ij}=1 \tag{3}$$

$$W_{ij} \geq 0 \qquad\qquad j = 1,2,...,J \tag{4}$$

The objective function of the Ng model is presented by equation (1). The goal of this objective function is to maximise the score of the best supplier. Constraint (2) ensures the weight values are in the same sequence as the ranking. Constraint (3) is about normalisation. X_{ij} is the score of j^{th} criteria of supplier *i* as shown in table-1.The converted values used in the study are calculated using equation (5) for normalisation (see Table-2) [3].

$$Y_{ij} = \frac{X_{ij} - Min_{i=1,2,\ldots,J}(X_{ij})}{Max_{i=1,2,\ldots,J}(X_{ij}) - Min_{i=1,2,\ldots,J}(X_{ij})} \tag{5}$$

2.2. APPLICATION

We consider a supply chain network of enterprise *XYZ*. The manufacturer which produces chairs. The data used are as in Şenyiğit and Soylemez study [7]. Enterprise *XYZ* has a *30.000* units capacity and *20.000* TLs for fixed operating costs for the product. The production cost for *XYZ* for each chairmodel-1 is *7* TLs. The *enterprise* has *3* distribution centres (DCs) in three different countries (Turkey, Iran and France). There are three groups of customers which are in the same country as the *DC*s are assumed.

All suppliers have finite capacities. All raw materials have to purchase from related suppliers for the production of Chairmodel-1. Chairmodel-1 has four different raw materials (carcass groups, seat groups, sponges and packages). There are two different suppliers for each raw material (8 suppliers (4x2)). Only one supplier from two suppliers for each raw material must be chosen (4 suppliers from 8 suppliers). For this reason, the best supplier for each raw material of the Chairmodel-1 by the Ng model ($via\ \boldsymbol{\beta}_{si}$) is selected.

The data of suppliers for different criteria are shown in table-1. As is seen, the units of each criterion are different. Quality (*J1*) is a supplier selection criterion indicating what percentage of the Chairmodel-1s supplied by the supplier firms are in good condition. Price (*J2*) indicates the purchase price of the product. The unit is Turkish Liras. Distance (*J3*) is the distance of the suppliers to the firm in the unit of km.

Ng [3] emphasized that all measures were positively related to the score of a supplier. If there was a negatively related criterion, the transformation of negativity or reciprocal taking could be applied for conversions. A common scale for all measures was also an important issue. Ng stated that a particular criterion measure on a large scale might dominate the score. A reciprocal transformation of price and distance measures is taken so that the transformed values are positively related to the desired scores as in the Ng study [3].

The data are normalised which is shown in table-1 by equation (5). Table-2 showed the normalization results, the score of supplier *i* for raw material *s* and selected suppliers. The *0* and *1* values in table-2 were calculated by equation (5) for normalization. The score values in table-2 were found by Ng model. For example, there were two suppliers of sponge for the Chairmodel-1 (see table-2). The score of *I31* was *0.5* and the score of *I32* is *0*. The result showed *I31* to be better than *I32*. Therefore, we selected *I31* as the supplier of sponge for the Chairmodel-1. This example had been shown to facilitate understanding of the problem.

The manufacturer faces the optimization problem of determining the best supplier and purchasing amount from the best supplier while satisfying customers' demands and minimising the total cost (TC) of the *SMSCN* system. Thus, in this problem there are four kinds of costs must involve. These are; purchasing costs, transportation costs, production costs and fixed operating costs. The customer demands balance, product balance and raw materials' balance constraints are ensured by, in order, Constraint (7), Constraint (8) and Constraint (9).

Table 1. Data of suppliers for different criteria

S	I	J_1 (%)	J_2 (TL)	J_3 (KM)
S1	**11**	96	6.00	10
	12	94	5.90	6
S2	**21**	95	5.60	12
	22	96	5.70	18
S3	**31**	94	4.00	20
	32	95	4.10	5
S4	**41**	95	2.20	7
	42	94	2.00	15

Table 2. Transformed and normalised measures of suppliers under criteria and results of Ng model

S	I	J_1 (%)	J_2 (TL)	J_3 (KM)	S_{si}	β_{si}
S1	**11**	1	0	0	0.50	0
	12	0	1	1	1.00	1
S2	**21**	0	1	1	1.00	1
	22	1	0	0	0.50	0
S3	**31**	0	1	0	1.00	1
	32	1	0	1	0.67	0
S4	**41**	1	0	1	0.67	0
	42	0	1	0	1.00	1

2.3. MIXED INTEGER LINEAR PROGRAMMING

The objective function is *TC* of the *SMSCN* system and all intermediate variables 1260inimization (Equation (6)). The objective functions and constraints of the model are listed below as:

$$\text{Min } \sum_s \sum_i C_{si}X_{si}\beta_{si} + \sum_s \sum_i SC_{si}X_{si}\beta_{si} + \sum_m C_mY_m + \sum_m \sum_n C_{mn}Z_{mn} + \sum_m PC_mY_m + \sum_m F_m + F \quad (6)$$

Subject to

$$(1 - V_m)Z_{mn} \le D_n \quad (7)$$

$$(1 - U_p)Y_p \le Z_{mn} \quad (8)$$

$$w_s(1 - T_{si})\sum_i X_{si}\beta_{si} \le \sum_m Y_m \quad (9)$$

$$Z_{mn} \le K_m \quad (10)$$

$$\sum_m Y_m \le P \quad (11)$$

$$X_{si}\beta_{si} \le K_{si} \propto_{si} \quad (12)$$

$$X_{si}, Y_m, Z_{mn} \ge 0 \quad (13)$$

$$\propto_{si}, \beta_{si} = \{0, 1\} \quad (14)$$

DCs, factory production and suppliers' capacity limits constraints are maintained by, in order, Constraint (10), Constraint (11) and Constraint (12). Constraint (13) provides that decision variables must be greater than *0*. Constraint (14) is about binary variables. The capacity limits on raw material *s* of supplier *i*, the transportation cost of raw material *s* from supplier *i* to factory, the purchasing cost of raw material *s* from supplier *i* to the factory and the average defect rate of supplier *i* for raw material *s* are shown in table-3.

Table 3. The parameters of suppliers according to the raw materials [7]

S	I	K_{si} (Units)	C_{si} (TL)	SC_{si} (TL)	T_{si} (%)
	11	25.000	0.7	6.00	4
S1	**12**	25.000	0.6	5.90	6
	21	25.000	0.6	5.60	5
S2	**22**	25.000	0.6	5.70	4
	31	25.000	0.4	4.00	6
S3	**32**	25.000	0.6	4.10	5
	41	25.000	0.4	2.20	5
S4	**42**	25.000	0.4	2.00	6

The parameters such as transportation, purchasing, production, fixed operating costs, average defect rates, capacities of suppliers, factory and DCs and the customer demands of enterprise XYZ are shown in table-4.

Table 4. The parameters of DCs and customers [7]

M	DC1	DC2	DC3
C_m (TL)	0.60	2.40	4.80
U_m (%)	2	2	1
K_m (Units)	60000	70000	80000
F_m (TL)	1000	5000	10000
C_{mn} (TL)	0.15	0.30	0.40
N	N1	N2	N3
D_n (Units)	1000	5000	10000
V_m (%)	1	1	0

3. RESULTS

The calculated total quantities of raw material *s* purchased from supplier *i* for the best and worst models were presented in Table-5. The result of the 1261ptimization of the *MILP* model of *SMSCN* of enterprise XYZ showed that *I12*, *I21*, *I31* and *I42* suppliers are the best suppliers while *I11*, *I22*, *I32* and *I41* suppliers are the worst suppliers. *17324.4* units carcass groups (*S1*), *17142.4* units seat groups (*S2*), *17324.4* units sponges (*S3*) and *17324.4* units packages (*S4*) are purchased from the best suppliers for each raw material. *16963.85* units *S1*, *16963.85* units *S2*, *17142.4* units *S3* and *17142.4 S4* are purchased from the worst suppliers for each raw material for getting the worst model solution. The reason for the diversity in the number of seat groups is the average defect rate of the best supplier of the seat group raw material (*5%*). The total cost of the best model for *SMSCN* of enterprise *XYZ* is *553926. 6* TLs whereas total cost of the worst model is 562834.9 TLs.

Table-6 presents the calculated quantities for *DCs* and customers for the best model and worst model. *16,285.3* Chairmodel-1s must be produced at the factory for all models. As there was no fractional transportation, it turned into an integer-valued solution by rounding up. For that reason, we had to revise the solution that we obtained from *MILP*.

Table 5. The calculated total quantities of raw material *s* purchased from supplier i

		Best Model	Worst Model
S1	X11	0	16963.85
	X12	17324.4	0
S2	**X21**	17142.4	0
	X22	0	16963.85
S3	**X31**	17324.8	0
	X32	0	17142.4
S4	X41	0	17142.4
	X42	17324.8	0

Table 6. The calculated quantities for DCs and customers

		M\N	
	DC1	**DC2**	**DC3**
$\mathbf{Y_m}$	1030.7	5153.6	10101
$\mathbf{Z_{mn}}$	1010.1	5050.5	10000

Table 7. The corrected quantities for DCs and customers

		M\N	
	DC1	**DC2**	**DC3**
$\mathbf{Y_m}$	1032	5155	10101
$\mathbf{Z_{mn}}$	1011	5051	10000

Table 8. The corrected total quantities of raw material *s* purchased from supplier *i*

		Best Model	Worst Model
S1	X11	0	16964
	X12	17328	0
S2	**X21**	17146	0
	X22	0	16964
S3	**X31**	17328	0
	X32	0	17143
S4	X41	0	17143
	X42	17328	0

The corrected quantities for DCs and customers are shown in Table-7. Table-8 presents the corrected total quantities of raw material *s* purchased from supplier *i* both best model and worst model. In the application, *16288* units product must be produced to satisfy the total demands of customers.

4. CONCLUDING REMARKS AND FUTURE STUDIES

As the enterprises continue to exist, it is essential for them work with the suppliers that reduce the total system costs. Besides suppliers offering the lowest prices which are not generally accepted as ‘‘efficient sourcing’’, multi-criteria must be in supplier selection with optimum purchasing amount to reduce the total costs and satisfy all customer demands. The motivation of this study and the multi-criteria supplier selection and purchase problem (*MCSSPP)* are stemmed from the request of the enterprise *XYZ* which is a firm from the Turkish furniture industry in Kayseri, Turkey. This paper addressed the problem and presented the solution approach proposed to the problem. To apply the solution approach to *MCSSPP*, a chair model that has four different raw materials was selected as an application product from the products of enterprise *XYZ*. For each raw material, the enterprise *XYZ* had two suppliers. So, each raw material must be procured from one of the suppliers. The problem was modelled by supplier selection and system cost optimization phases. In supplier selection phase, the best supplier was determined by the Ng model for each raw material. It was found that *I12*, *I21*, *I31* and *I42* were the best suppliers while *I11*, *I22*, *I32* and *I41* were the worst suppliers. After the best and worst suppliers were determined, the single-product multi-echelon supply chain network (*SMSCN)* of enterprise *XYZ* was first formed by mixed integer linear programming (*MILP)* in the system cost optimization phase. Then, the *SMSCN* was optimized, and the optimum results were corrected to integer values according to the defect rates among echelons. The final model was accepted as the best model. The total cost of the best model was *553926.6* TLs. Same procedure were applied for the worst suppliers. The total cost of the worst model was calculated as 562834.9 TLs. As a conclusion, the total cost of *SMSCN* of enterprise *XYZ* was reduced by *8908.3* TLs (%*1.61*). As a future research, it is planned to improve this study by multi products, sustainability, and green supplier selection perspectives. The proposed approach can be applied to wide range of firms to solve their *MCSSPPs* and to improve their competitiveness.

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