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Vendor Selection and Supply Quotas Determination by using Revised Weighting Method and Multi-Objective Programming Methods

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***Abstract*—**In this paper a new methodology for vendor selection and supply quotas determination (VSSQD) is proposed. The problem of VSSQD is solved by the model that combines revised weighting method for determining the objective function coefficients, and a multiple objective linear programming (MOLP) method based on the cooperative game theory for VSSQD. The criteria used for VSSQD are: (1) purchase costs and (2) product quality supplied by individual vendors. The proposed methodology has been tested on the example of flour purchase for a bakery with two decision makers.

***Keywords*—**Cooperative game theory, multiple objective linear programming, revised weighting method, vendor selection.

I. Introduction

THE problem of vendor selection and supply quotas determination is the key element in the purchasing process in manufacturing. If all the selected vendors are able to meet the buyer's requirements completely, then the selection process is based only on the selection of the most suitable vendor in terms of purchasing costs, product quality, vendor reliability, etc. However, practice shows that it is not advisable to rely on one vendor only. Therefore the management of the purchasing company generally enters into contracts with several vendors. Their number usually ranges from two to five for each sort of material. Also, there are cases when no vendor can meet the buyer's demand, or will not do it in order to protect his own business interests.

The purchasing company must decide which vendors they should contract with and they must determine the appropriate order quantity for each vendor selected.

In this paper we discuss the supplier selection problem and supplied quotas determination for the companies which purchase flour for producing bread and bakery products. Before the selection process starts the decision makers (DM's) should define the minimal and maximal number of the suppliers from which they would purchase the flour, and the maximal quantity purchased from an individual vendor.

The proposed methodology combines two methods used in operational researches: revised weighting method used to determine the coefficients of complex objective functions (quality), and a multiple objective integer linear programming (MOILP) method to provide the final selection and the quantity supplied from a particular vendor.

To test the proposed methodology we solve a practical VSSQD problem in a bakery with two decision makers, one for the purchasing costs and one for the product quality supplied by individual vendors. The revised weighting method is used to determine the coefficients of the quality objective function which is complex with three levels and more attributes on the second and third levels. The MOLP model is solved by using a MOLP method based on the idea of cooperative game theory, which helps the decision makers in the process of the model solving to find the preferred solution. The constraints in the multiple objective programming model are: (1) the total demand, (b) the minimal and maximal number of vendors and (3) the limitations of vendor capacities.

Vendor selection and supplied quotas determination is an important issue dealt with by numerous researchers. Great efforts have been made to define appropriate models for vendor selection and determination of supply quotas from the selected vendors and to apply the adequate methods to solve such models.

The literature dealing with vendor selection uses various methods. Among the numerous studies dealing with this topic we will mention some more important ones. A large number of papers include AHP method in combination with the multi-objective linear programming methods. Thus, for instance, [1] use the AHP method in combination with linear programming. Reference [2] uses the AHP and goal programming. Reference [3] uses the AHP method and fuzzy linear programming, while [4] and [5] use only fuzzy goal programming for that purpose. Reference [6] uses AHP and fuzzy linear programming to solve the vendor selection and supplied quotas determination problem in a bakery. A smaller number of papers combine revised weighting method and multi objective linear programming methods. Reference [7] solves the vendor selection and supplier quotas determination problem by using the revised weighting method and fuzzy multi-criteria programming. However, there are no methodologies which simultaneously use revised weighting method and a multiple objective linear programming method based on the cooperative game theory to solve the VSSQD problem.

The main idea of the study in this paper is to create a new methodology for vendor selection and supply quotas determination to solve specific problems, which would be

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more objective and easier to use compared to previously used methodologies. There are criteria which by their nature can be complex (they have a hierarchical structure with a number of sub-criteria, sub-criteria have their sub-sub-criteria, etc.). It has been shown that these criteria can be simplified by the application of AHP method or the revised weighting method [6], [7]. In this paper we suggest developing the process of choice preferred solution according to the idea of cooperative games, so that there is one DM for each objective function. The process of problem solving develops by solving two linear programming (LP) problems (one for each DM), so that DMs gradually reduce the values of their objective functions. The solving process is finished when for both models approximately the same value of objective functions is obtained. The solution reached in this way is also the Nash equilibrium [8].

The rest of the paper is organized as follows: We will first present the methodology of vendor selection and determination of supply quotas by revised weighting method, and a multiple objective linear programming method based on cooperative game theory. Then the proposed methodology will be tested on the example of vendor selection by a bakery. In the conclusion we will point to the advantages of using the proposed methodology in comparison to the use of revised weighting method combined with the goals satisfactory method [9].

II. Methodology of Vendor Selection and Determination of Supplied Quantity

We suppose that in the process of the problem solving there is one decision maker for each objective function: cost and quality. For vendor selection and determination of supply quotas we will use the revised weighting method and multiple objective linear programming model solved by a MOLP method based on the cooperative game theory. The revised weighting method is used to determine the coefficients of complex criteria functions. The main steps in the proposed model are:

1. Determining criteria for vendor selection,
2. Applying revised weighting method to determine the variables' coefficients in the complex objective function,
3. Building and solving the multiple objective linear programming model to determine marginal solutions,

3.1. Determine optimal (marginal) solutions for the objective functions,

3.2. Solving the MOLP model by the method based on the cooperative games theory.

A. *Determining Criteria for Vendor Selection*

The first step in the proposed methodology is selection of criteria for vendor selection. Numerous criteria are stated in literature and their selection depends on the concrete problem [10]. The total purchasing costs in a particular period, product quality offered by particular vendors, and vendor reliability should be noted as the most important criteria for supplier selection. Each of these criteria is expressed through a number of sub-criteria, which can further be expressed through a number of sub-sub-criteria, etc. This reveals the hierarchical structure of criteria for vendor selection, which enables the application of the revised weighting method to solve the problem of complexity criteria functions [11].

B. *The Revised Weighting Method*

We will give a brief outline of the basic propositions of this multi-criteria method used in a large number of factual cases.

The main idea of the weighting method as presented in [12] and [13] is to relate each criteria function with the weighting coefficient and to maximize/minimize the weighted sum of the objectives. In that way the model containing several criteria functions is transformed into the model with one criteria function. It is assumed that the weight coefficients w_j are real numbers so that $w_j \geq 0$ for all $j = 1,\ldots,k.$ It is also assumed that the weights are normalized, so that $\sum_{j=1}^{k} w_j = 1.$ Analytically presented, the multi-criteria model is modified into a mono-criterion model and is called the weighting model:

$$\max/\min \sum_{j=1}^{k} w_j f_j(\underline{x}) = \sum_{j=1}^{k} \sum_{i=1}^{n} w_j c_{ij} x_i \qquad (1)$$

$$\text{s.t.} \quad \underline{x} \in X, \qquad (2)$$

where $w_j \geq 0$ for all $j = 1,\ldots,k,$ $\sum_{j=1}^{k} w_j = 1.$ To make the weighting coefficients w_j express the relative importance of criteria functions f_j we propose linear transformation of criteria functions coefficients [7]. To allow addition of weighted criteria functions we have to transform all of them either into functions that have to be maximized or into functions to be minimized. Linear transformation of criteria functions coefficients that have to be maximized is performed in the following way:

$$c_{ij}^{'} = c_{ij} / c_j^{*}, \qquad (3)$$

where $c_j^{*} = \max_i c_{ij}.$ Obviously $0 \leq c_{ij}^{'} \leq 1.$ The criteria functions that have to be minimized will be transformed into functions to be maximized by taking reciprocal values of coefficients c_{ij}: $1/c_{ij}.$ Then

$$c_{ij}^{'} = \frac{1/c_{ij}}{\max_i (1/c_{ij})} = \frac{\min_i c_{ij}}{c_{ij}} = \frac{c_j^{\min}}{c_{ij}}. \qquad (4)$$

Now we will normalize the coefficients $c_{ij}^{'}$ so that their sum equals one.

$$c_{ij}^{''} = \frac{c_{ij}^{'}}{\sum_{i=1}^{n} c_{ij}^{'}}, \quad j = 1,\ldots,k. \qquad (5)$$

The transformations (3)-(5) allow us to obtain the weighted sum of criteria functions in which the weights reflect the relative importance of criteria functions.

In this paper we use the revised weighting method to reduce the complex criteria functions. According to this method, the normalized original criteria functions are divided into groups so that the linear combination of criteria functions in each group forms a new criteria function while the linear combination of new criteria functions form a further criteria function, etc. In this way we obtain a model with a reduced number of criteria functions. According to this each Pareto optimal solution of the new model is also Pareto optimal solution of the original model [9].

C. *Multiple Objective Linear Programming (MOLP) Model*

The general form of MOLP can be defined in the following way:

If $Z_k(x) = c_k x, \quad x \in R^n,\ c_k \in R^n,$ then

$$\text{Max } Z(x) = (z_1(x), z_2(x), \ldots, z_K(x)), \tag{6}$$

$$\text{s.t.} \quad Ax \leq = \geq b, \tag{7}$$

$$x \geq 0, A \in R^{m \times n}, b \in R^m. \tag{8}$$

Thus, the model (6)–(8) contains K linear functions and m constraints, with the variables which must be nonnegative. The variables of the model can be continuous, integer and binary or their combination.

Solving the model (6)-(8) so that each of the objective function is separately maximized we will obtain marginal solutions of this model. Since the objective functions in MOILP models are mutually conflicting, the values of objective functions will be significantly different for marginal solutions.

DMs almost certainly will not choose any of the obtained marginal solutions, but will look for a compromise solution which will satisfy their preferences to objective function values.

To find compromise solution we can use a number of multiple objective linear programming (MOILP) methods. However, MOILP methods have different efficiency and give different solutions, so the problem of choosing the appropriate method may occur.

D. MOILP Method Based On the Cooperative Game Theory

To apply the game theory model to the bi-objective economic balance problem, we set two decision makers as two players: player 1 who maximizes the function z_1 on the given set of constraints, and player two who maximizes the function z_2 on the given set of constraints [14]. Therefore, we form two models:

$$\max z_1 = c_1 x, \tag{9}$$

$$\text{s.t. constraints (7) – (8)}, \tag{10}$$

and

$$\max z_2 = c_2 x, \tag{11}$$

$$\text{s.t. constraints (7) – (8)}. \tag{12}$$

Each player wants to know their maximum and minimum values from the optimization of each individual single objective function on the set of constraints. Since neither of DMs can realize the maximum of their objective functions, they have to negotiate to determine and choose the solution which will be acceptable to each of the players (DMs). From the pay-off table we can see maximum and minimum values (z_1 and z_2) for each player (this is a negotiation interval and also a pay-off in the game theory analysis). Thus, the range of the maximum and minimum values (z_1, z_2) for each player can be determined as follows:

For player 1:

$$z_1^{\min} \leq z_1(x) \leq z_1^{\max}. \tag{13}$$

For player 2:

$$z_2^{\min} \leq z_2(x) \leq z_2^{\max}. \tag{14}$$

The initial MOLP results for each player include a pair of “simulated” $z_1(x)$ and $z_2(x)$ values. Once the range is known, the initial round of bargaining begins. Each player sets the objective values $z_1^{\max}$ or $z_2^{\max}$ as z_1 goal and z_2 goal, respectively. The process of problem solving begins by solving the next two models, one for each DM. In the model for player 1 the constraint of minimal value of objective function for player 2 is added, while in the model for player 2 the constraint of minimal value of objective function for player 1 is added.

For player 1 the strategy is

$$\max z_1(x) \tag{15}$$

$$\text{s.t. constraints (7) – (8)} \tag{16}$$

$$z_2(x) \geq z_2^{\text{goal}}. \tag{17}$$

And for player 2:

$$\max z_2(x) \tag{18}$$

$$\text{s.t. constraints (7) – (8)}, \tag{19}$$

$$z_1(x) \geq z_1^{\text{goal}}. \tag{20}$$

However, since the goals of player 1 and player 2 are in conflict, at the beginning neither player will be satisfied with the results of the other player’s objective function maximization, i.e. the multiple objective integer linear game model (MOILGM) result for player 1 will be far under their objective values, and the corresponding value for player 2 will be far below their goal. Consequently, the players will begin a series round of bargaining and concessions. It is expected that, during the first bargaining round, the players put their objective values very close to $z_1^{\max}$ and $z_2^{\max}$ to see what happens. Besides, neither player will be satisfied with the results after the second round of negotiations. Consequently, a series of bargaining and concessions will be conducted by adjusting each player's objective values (i. e. player 1 and player 2 will reduce their expectations of the goal's values) [14].

After further negotiations, the difference between the reset objective values and the multiple objective integer linear programming game theory model (MOILPGM) results becomes less divergent. The bargaining process continues until final solution of z_1^* and z_2^* is identified as follows:

For player 1:

$$z_1^* \le z_1^{\text{goal}} . \tag{21}$$

For player 2:

$$z_2^* \le z_2^{\text{goal}} . \tag{22}$$

The solution value (z_1^* and z_2^*) is known as the Nash equilibrium [8].

In short, the MOLPGM modelling is performed as follows:

1. Set initial goal and strategy for each player independently by referring to pay-off ((13) and (14)).
2. Solve the optimization models ((15)-(17) and (18)–(20)); if the solutions are satisfactory to all players, proceed to step 4; if not, proceed to step 3.
3. Re-set goal for each player independently and return to step 2.
4. Nash equilibria are achieved ((21) and (22)) and the game is over [14].

III. Case Study

A. *Criteria for Vendor Selection*

Vendor selection and determination of quantities supplied by the selected vendors is a multi-criteria problem. A large number of criteria that can be used in vendor selection is offered in literature. Which criteria will be chosen by the decision maker depends on the kind of the problem to be solved. In this study we consider criteria that can be used by producers of bakery products when selecting flour vendors. More about the criteria can be seen in [6].

B. *Data Required for Vendor Selection and Determination of Supply Quotas*

Here we present the example of vendor selection for a bakery. It is to be noted that in production of bread and bakery products the purchase of flour is contracted for the period of one year, from harvest to harvest, which usually does not correspond to the calendar year. After the harvest flour producers have the information on the available wheat quantity, price and quality which allows them to define the price, quality and quantity of flour they can supply in the subsequent one-year period [6].

In the one-year period the bakery plans to consume 6000 tons of flour Type 550. The company contacts 6 potential flour suppliers and defines the upper limit of flour supplied by a single vendor in the amount of 4000 tons. The management has decided to sign a contract of delivery with at least two suppliers. Besides, they decided that the number of suppliers may not exceed four. The proposed prices of flour and transportation costs (Criterion C1) are shown in Table I. The potential vendors supply data on flour quality which they have to maintain throughout the contract period (Criterion C2). It is to be noted that the quality of flour depends on the wheat sort and quality and on technology used in flour production. Table II indicates flour quality. The weights expressing the relative importance of criteria and sub-criteria are given in brackets, and are determined by the decision maker where in every group of sub-criteria the sum of weights is 1.

TABLE I
PURCHASING COSTS FOR FLOUR TYPE 550

Vendor	Purchasing price in Euros/ton (B1)	Transportation cost in Euros/ton (B2)	Total purchasing costs per ton in Euros
1	240	20	260
2	215	25	240
3	230	20	250
4	275	15	290
5	200	10	210
6	260	35	295

TABLE II
QUALITY INDICATORS FOR FLOUR TYPE 550

Quality indicators	Criteria weights	Vendor					
		1	2	3	4	5	6
General characteristics of flour (A1)	**(0.20)**						
Moisture in % (B3)	min (0.30)	14.2	14.56	13.6	14.1	13.09	14.85
Ash in % (B4)	min (0.20)	0.56	0.55	0.59	0.51	0.54	0.48
Acidity level in ml/100 grams (B5)	min (0.10)	1.8	1.8	1.6	1.8	1.5	1.5
Wet gluten in % (B6)	max (0.40)	26.5	26.8	29.4	24.6	24.7	28.7
Farinograph (A2)	**(0.30)**						
Water absorption in % (B7)	max (0.40)	60.2	56.3	57	56	57.8	55.8
Degree of mellowness in FJ (B8)	min (0.60)	55	30	33	40	80	50
Extensigraph (A3)	**(0.30)**						
Energy u cm^2 (B9)	max (0.40)	110	102.1	128	104.3	98	133
Elasticity in mm (B10)	max<190 (0.30)	163	146	167	161	175	165
Resistance (B11)	min (0.30)	380	400	605	390	330	395
Amylograph (A4)	**(0.20)**						
Peak viscosity in BU (B12)	max (1.00)	1110	1015	1255	1610	1126	1460

C. *Application of Revised Weighting Method*

Considering the data from Tables I-III we form a hierarchical structure of goals and criteria for vendor selection. The hierarchical structure in our example consists of five levels. Level 1 represents the vendor general efficiency (or total value of purchasing - TVP), Level 2 represents criteria for vendor selection, Level 3 represents sub-criteria of criteria from level 2, Level 4 represents sub-criteria of the sub-criteria from level 3, and Level 5 represents the available alternatives (vendors).

After the decomposition of the problem and formation of the hierarchical structure of goals and criteria, we have applied a revised weighting method to calculate the coefficients of cost and quality functions. By application of the relation (3) and (5) the cost function coefficients are normalized. The following weights are obtained and presented in Table III:

TABLE III
NORMALIZED COEFFICIENTS OF COST FUNCTION

Variable	Coeff. c'_{i1}	Coeff. c''_{i1}
x_1	0.881356	0.168285
x_2	0.813559	0.15534
x_3	0,847458	0.161812
x_4	0.983051	0.187702
x_5	0.711864	0.135922
x_6	1.0	0.190939

The quality function has a hierarchical structure and has to be maximized. Sub-criteria B3 to B12 are grouped into 4 sub-criteria sets. According to the data on coefficients weights, their linear transformation and normalization into the interval $[0,1]$ is carried out. The normalized coefficient values are shown in Table IV:

TABLE IV
NORMALIZED COEFFICIENT VALUES WITH VARIABLES FOR SUB-CRITERIA B3-B12

Var.	c''_{iB3}	c''_{iB4}	c''_{iB5}	c''_{iB6}	c''_{iB7}	c''_{iB8}	c''_{iB9}	c''_{iB10}	c''_{iB11}	c''_{iB12}
x_1	0.165	0.158	0.153	0.165	0.175	0.131	0.163	0.167	0.179	0.147
x_2	0.161	0.162	0.153	0.167	0.164	0.239	0.151	0.149	0.170	0.134
x_3	0.172	0.151	0.172	0.183	0.166	0.218	0.190	0.171	0.112	0.166
x_4	0.166	0.177	0.153	0.153	0.163	0.179	0.154	0.165	0.174	0.213
x_5	0.179	0.165	0.184	0.154	0.168	0.090	0.145	0.179	0.194	0.149
x_6	0.158	0.186	0.184	0.179	0.163	0.144	0.197	0.169	0.172	0.193

Using the data on weighting coefficients with variables of grouped sub-criteria and weighting coefficients with sub-criteria A1, A2, A3 and A4, and by applying the relation (1) we calculate the coefficients with criterion C2 variables:

TABLE V
NORMALIZED COEFFICIENT WEIGHTS WITH QUALITY CRITERION VARIABLES

Variable	Coeff. c''_{i2}
x_1	0.156995
x_2	0.168946
x_3	0.174893
x_4	0.175744
x_5	0.150379
x_6	0.173042

D. MOILP Model Building and Solving

We should first form a MOILP model with two objective functions and nineteen constraints. Considering the data on normalized coefficient weights with variables of cost, and quality functions, the total demand for flour in the given period, limited quantities supplied by single vendors and the constraint of the minimal and maximal number of vendors, the following MOILP model is formed:

Minimization of purchasing cost

$$\text{Min } z_1 = 0.168285x_1 + 0.15534x_2 + 0.161812x_3 + 0.187702x_4 + 0.135922x_5 + 0.190939x_6 \tag{23}$$

Maximization of flower quality

$$\text{Max } z_2 = 0.156995x_1 + 0.168946x_2 + 0.174893x_3 + 0.175744x_4 + 0.150379x_5 + 0.173042x_6 \tag{24}$$

s.t.

Total needed flour quantity, limited quantities supplied, vendor number constraints, and non-negativity of variables are shown as:

$$\sum_{j=1}^{6} x_j = 6000 \tag{25}$$

$$x_j \le 4000,\ j = 1,2,...6 \tag{26}$$

$$x_j \le M \cdot y_j \quad j = 1,2,...,6 \tag{27}$$

$$-x_j + M \cdot y_j \le M - x_j^{\min},\ j = 1,2,...,6 \tag{28}$$

$$2 \le \sum_{j=1}^{6} y_j \le 4 \tag{29}$$

$$x_1, x_2, x_3, x_4, x_5, x_6 \ge 0 \text{ and integer; } y_1, y_2, y_3, y_4, y_5, y_6 \in \{0,1\}. \tag{30}$$

y_j are artificial binary variables and they show us whether supplier j has been chosen. These variables are related to variables x_j, in such way that if the problem solution contains variable x_j, then variable y_j must equal 1, and if in the problem solution variable x_j is zero then y_j must also be zero, and vice versa. M is a very big number, and $x_j^{\min}$ (j = 1, 2, ..., 6) is the minimal value which a variable x_j can have if a variable y_j is included in the solution.

Model (23)–(30) is a multi-objective integer linear programming model where the coefficients of the objective functions are obtained in the first stage of problem solving by application of the revised weighting method.

Model (23)–(30) is first solved by integer linear programming method optimizing separately each of the two objective functions on the given set of constraints. The results are given in the Payoff table:

TABLE VI
PAYOFF VALUES

Solution	Min $z_1(x)$	Max $z_2(x)$
X_1*	854.368	939.408
X_2*	1074.432	1052.762

It can be seen that the obtained solutions differ and that DM's have to choose a compromise solution. This work proposes methodology for vendor selection and determination of supply quotas by solving MOILP model applying MOILPGM. Therefore, the solution process is contained form several steps.

Solving the problem by applying the MOILPGM method started informing each DMs (players) about the maximal and minimal values of the objective functions, for each player.

$$854.368 \le z_1 \le 1074.432, \tag{31}$$

$$939.408 \le z_2 \le 1052.762. \tag{32}$$

Subsequently, DMs gradually reduce the aimed objective function values. It is normal that each DM wants to achieve the highest value possible for their objective function.

According to this the following linear programming problems are solved:

For player 1 the strategy is

$$\min z_1(x) \tag{33}$$

$$\text{s.t. constraints (25)} - (30) \tag{34}$$

$$z_2(x) \ge z_2^{\text{goal}}. \tag{35}$$

and for player 2:

$$\max z_2(x) \tag{36}$$

$$\text{s.t. constraints (26)} - (31) \tag{37}$$

$$z_1(x) \le z_1^{\text{goal}}. \tag{38}$$

After the first round of negotiations (both DMs reduced their goals) the obtained results do not satisfy any one the DM. After that the DMs continue reducing their goals and try to solve the above models once again.

The process of reducing goals and model solving continues until the result is obtained with which both DMs are satisfied. In our case the satisfying solution (Nash equilibrium) has been reached after four steps. The obtained solutions by steps are shown in Table VII.

TABLE VII
THE STEPS OF PROBLEM SOLVING BY MEANS OF IDEA OF COOPERATIVE GAMES

Step	max z_1 s.t. z_2 ≥	max z_2 s.t. z_1 ≤	x_1	x_2	x_3	x_4	x_5	x_6	z_1	z_2
1	1045	-	0	1000	3133	1867	0	0	1012.71	1044.96
	-	860	0	2290	0	0	3710	0	860.00	944.79
2	1015	-	0	1655	3345	0	1000	0	934.27	1015
	-	870	0	2805	0	0	3195	0	870.00	954.35
3	985	-	0	3135	1000	0	1865	0	902.30	985.00
	-	880	0	3320	0	0	2680	0	880.00	963.92
4	970	-	0	3648	0	0	2352	0	886.36	970.00
	-	885	0	3578	0	0	2422	0	885.00	968.71

After four steps the Nash equilibrium solution is obtained. In other words, the solution obtained by minimizing function z_1 in the 4th step differs slightly from the solution obtained by maximizing function z_2 in the 3rd step. The process of model solving stops so the DMs choose one of the obtained solutions. Both solutions give approximately the same values for both objective functions.

To show that the proposed methodology is better than the application of standard MOILP methods in solving this problem, model (23)-(31) has been solved by ε – Constraints MOILP method [9]. First, we maximize function z_1, while putting function z_2 in the constraints set, gradually reducing the value of the objective function, and then we maximize function z_2 placing function z_1 in the constraints set, gradually reducing its goals. So, the following model has been solved:

$$\min z_1 = c_1 x \tag{39}$$

$$\text{s.t. } z_2 = c_2 x \ge z_2^{\max} - \varepsilon \tag{40}$$

$$\text{constraints (25)} - (30) \tag{41}$$

The results of the model (39)-(41) are shown in Table VIII.

TABLE VIII
NON-DOMINATED SOLUTIONS OF THE MODEL (39) – (41)

Step	max/ min	z_2 ≥	z_1 ≥	x_1	x_2	x_3	x_4	x_5	x_6	z_1	z_2
1	z_1	1045	-	0	1000	3133	1867	0	0	1012.74	1045.00
2	z_1	1025	-	0	4000	2000	0	0	0	944.98	1028.57
3	z_1	1005	-	0	3337	1663	0	1000	0	923.4	1005.01
4	z_1	985	-	0	3135	1000	0	1865	0	902.31	985.00
5	z_1	965	-	0	3378	0	0	2622	0	881.13	965.00
6	z_1	945	-	0	2301	0	0	3699	0	860.22	945
7	z_2	-	860	0	2290	0	0	3710	0	860.00	944.79
8	z_2	-	870	0	2805	0	0	3195	0	870.00	954.36
9	z_2	-	880	0	3320	0	0	2680	0	880.00	963.92
10	z_2	-	890	0	3835	0	0	2165	0	890.00	973.48
11	z_2	-	900	0	3017	1000	0	1963	0	900.00	982.80
12	z_2	-	910	0	3532	1000	0	1468	0	910.00	992.36
13	z_2	-	920	0	3860	1140	0	1000	0	920.00	1001.89

The non-dominated solutions from Table VIII are presented to the decision makers, from which they should choose the preferred solution. The choice of the preferred solution depends on the decision makers' preferences. Since, there are two DMs in our case; the decision based on the data from Table VIII is not simple. It is difficult to expect that the DMs would simply agree on the objective function values which they should reach by choosing one of the compromise solutions.

Consequently the idea of cooperative games significantly helps the DMs to choose the preferred solution.

IV. CONCLUSION

Solving the specific problem by application of the proposed methodology we can make a number of conclusions presenting the advantages of using the revised weighting method and a MOILP method based on the idea of cooperative games in comparison to the other similar methodologies.

The revised weighting method allows efficient reducing of complex criteria functions into simple ones. For DMs, it is easier to determine weighting coefficients if they deal with few criteria functions than if they deal with a large number of them. So if there is a large number of criteria and sub-criteria, there is a higher probability of error in determining the weighting coefficients.

The simplicity of using is the main advantage of the proposed methodology.

Solving the proposed MOILP model enables the efficient application of the idea of cooperative games in the process of finding the preferred solutions for the decision makers. Here decision maker compares only two objective functions and chooses the preferred solution in the process of negotiation with the other DM. The obtained preferred solution is also Nash equilibrium.

For the DMs it is easier to choose the preferred solution of VSSQD problem by means of the proposed methodology than by the methodology which includes the revised weighting method and $\varepsilon-$constraints method.

Further improvements of the proposed methodology of vendor selection and supply quotas determination problem in terms of dynamic process and simultaneous application of quantity discounts as well as discount of quantity value in a particular period will be the subject of our future research.

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