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A combined approach for equipment selection: F-PROMETHEE method and zero–one goal programming

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ABSTRACT

With the labor and material, equipments will be used in production processes, are one of the essential components of the production systems. Equipments used in production process are an important subject, effecting the system efficiency, the labor effectiveness and the product quality, and using inappropriate equipment effects all of this issues negatively. Equipment selection is a very important point for an efficient production system and is a complex and exhaustive problem necessitating the most proper selection among the various types of equipments seeming almost identical, generally. Therefore, an equipment selection problem is a multi-criteria decision making problem entailing taking into account of several criteria and generally involving linguistic datas. In this study, a multi-criteria decision making problem compromising a ranking due to criterias expressed in a linguistic way, concerning a welding machine selection problem of a company is handled. The vagueness of the linguistic terms in the evaluation process required employment of fuzzy numbers and accordingly the fuzzy version of PROMETHEE method, which is a multi-criteria ranking technique, is applied to the selection problem. The information obtained from F-PROMETHEE results is then used as a constraint in formulating a zero–one goal programming model. We demonstrated how a combined F-PROMETHEE and ZOGP model can be used for a real world application problem as an aid for equipment selection.

1. Introduction

One of the main problems faced while configuring or reconfiguring manufacturing systems is to rank alternative designs taking into account all the different aspects involved (both tangible and intangible) (Manassero, Semeraro, & Tolio, 2004). The early stages of design are characterized by imprecise and incomplete information about the features and the properties of targeted product or process. Equipment selection is one of the decisions to be taken in an initial phase of design (Kralawski, Pedrycz, & Nyström, 1999). Multi-attribute equipment selection is a very important activity for an effective manufacturing system. The satisfaction of customer requirements forces companies to become more sensitive and to make deep analyses in selecting equipment (Kulak, Durmusoglu, & Kahraman, 2005). Furthermore, a proper equipment selection is a very important activity for the manufacturing systems due to the fact that improper equipment selection can negatively affect the overall performance and productivity of a manufacturing system. In addition to this, equipment selection has a major effect on the companies' global competitiveness (Dağdeviren, 2008) and is also an important decision-making point for the design of a flexible manufacturing system (Kulak et al., 2005).

Using proper equipment can enhance the production process, provide effective utilization of manpower, increase production, and improve system flexibility (Dağdeviren, 2008). The selection of oversized equipment can disturb the company's cash flow and also the problems such as excessive inventory and idle equipment can be met. On the contrary, the selection of under-sizing equipment cannot fulfill requested quality levels and capacity requirements by customers (Kulak et al., 2005).

Selecting equipment under constrained operating conditions is a complicated task, due to many feasible alternatives and conflicting objectives (Chakraborty & Banik, 2006). In addition to these, as a wide variety of equipment is available today, each having a distinct characteristics and cost that distinguish from others, determination of the proper equipment for a designed manufacturing system is a very complicated decision (Kulak, 2005). The selection procedure is found to be unstructured, characterized by extensive domain dependent knowledge and requiring the application of an effective and efficient multi-criteria decision making tool (Chakraborty & Banik, 2006).

The criteria considered in an equipment selection can be categorized into two groups: costs and technical characteristics. In evaluating the equipment according to the technical characteristics or costs, the role of the equipment, which will be used in the

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manufacturing system, is very important (Kulak et al., 2005). Therefore, the selection of a new machine tool is a time-consuming and difficult process requiring advanced knowledge and experience and experience deeply. So, the process can be hard task for engineers and managers, and also for the machine tool manufacturer or vendor, to carry out (Ayag & Özdemir, 2006).

In the literature equipment selection problem is examined by employing the different types of methods. One of the recent studies is by Dağdeviren (2008) which uses an integrated approach of AHP for the purpose of determining the weights of criterias and analyzing the structure of the equipment selection problem, and PROMETHEE method for deciding the last ranking of alternatives and doing a sensitivity analysis with manipulations on weights, for a milling machine selection problem of an international company. As another instance to studies conducted under the headline of equipment selection, by İç and Yurdakul (2008) a decision support system (DSS) is developed using Fuzzy AHP and Fuzzy Technique for Order Preference by Similarity to Ideal Solution, which are extended versions of multi-criteria decision making approaches AHP and TOPSIS. Chakraborty and Banik (2006) employed AHP technique in selecting the optimal material handling equipment under a specific handling environment and performed sensitivity analysis to identify the most critical and robust criteria in the selection process in a similar study. In another study held by Ayag and Özdemir (2006) an intelligent approach is proposed, where both techniques; fuzzy logic and AHP are come together, referred to as fuzzy AHP, and was used for a machine tool selection problem. Solely, because of the vagueness and uncertainty of decision maker's judgements, fuzzy number logic is used in pairwise comparisons of AHP. Kulak et al. (2005) implemented convenient equipment selection by using information axiom under determined criteria. The unweighted and weighted multi-attribute axiomatic design approaches developed in their study include both crisp and fuzzy criteria and the selection process has been accomplished by aiding a software program called MAXD. Kulak (2005) developed a decision support system (FUMAHES: fuzzy multi-attribute material handling equipment selection) for material handling equipment selection considering factors influencing selection of material handling equipment such as effective use of labor, providing system flexibility, increasing productivity, decreasing lead times and costs, additionally a final decision is made for the most proper equipment among the alternatives of the same type using the information axiom of axiomatic design principles, for the cases of both complete and incomplete information. Another study was conducted by Kırmanlı and Erçelebi (2005) is about developing an expert system by using a KappaPC shell, for the equipment selection in surface mining, selecting the optimum hydraulic excavator and off-highway truck combination. Manassero et al. (2004) presented the first complete probabilistic extension to the AHP method providing the decision maker not only with information on the ranking of the alternatives but also the probability that the ranking remains stable even in the presence of uncertainty in the judgements, for an equipment selection problem of the Ferrari racing team. Başçetin (2003) used AHP for equipment selection, involving the selection of an optimal loading-hauling system from mine to a power station to be established in an open pit coal mine located Orhaneli, Turkey, in open pit mining. Chan, Ip, and Lau (2001) developed an intelligent material handling equipment selection system called MHESA, composing of a database, a knowledge-based expert system and an AHP model to choose the most favorable equipment type. Başçetin and Kesimal (1999) also demonstrated that the optimal decision can be able to be made by utilizing the AHP under the situation where more than one solution alternative and much more criterion are involved for equipment selection.

In this paper as distinct from the other methods proposed for equipment selection problems, we introduced an approach for selection of the most suitable equipment including both F-PROMETHEE, which is the integration of fuzzy number logic and PROMETHEE method, and 0–1 goal programming methods, and employing these methods respectively and conjointly. Briefly, we will demonstrate how a combined F-PROMETHEE and ZOGP model can be utilized to aid in equipment selection decision process by generating a solution considering F-PROMETHEE results as quantified values of qualitative expressions. Methods will be applied to a real world example according to the policies mentioned in the developed approach and the results of the applications will be compared at the last of evaluations. Constituted decision making team analyzed the structure of the equipment selection problem and determined the weights of criteria. We use F-PROMETHEE method to deal with the vagueness caused from the linguistic terms which are used in expressing the difference between the alternatives in the first phase of the comparisons of possible equipments. Then results obtained from this phase is used in the 0–1 goal programming method, which formulates the goals of the company as constraints and determines the best equipment alternative. As a result of this study, each of the deviations from targeted goals for both F-PROMETHEE and 0–1 goal programming methods will be examined, an equipment selection problem including the uncertainty of linguistic expressions in evaluation process is solved conveniently, and decision making process is analyzed in a detailed way.

This paper is divided into five sections. In Section 1, there is an introduction of studied problem and a literature research. In Section 2, proposed methodology is briefly described. In Section 3, proposed F-PROMETHEE and 0–1 GP integrated approach for equipment selection is presented and the stages of the proposed approach and steps are determined in detail. Section 4 involves a numerical application of proposed approach used for a real world example. The last section of this paper, Section 5, concludes the study with the discussion of the results and proceeds of the proposed approach.

2. Principles of fuzzy PROMETHEE and 0–1 goal programming methods

2.1. The fuzzy PROMETHEE method

Multiple criteria decision making (MCDM) is a powerful tool used widely for evaluation and ranking problems containing multiple, usually conflicting, criteria (Bilsel, Büyüközkan, & Ruan, 2006), as how it is in equipment selection problems. Several approaches have been proposed for multicriteria decision and the relevant methods were developed and applied with more or less success depending on the specific problem (Goumas & Lygerou, 2000). Selecting a proper method requires an insight analysis among available MCDM techniques. Among numerous methods of MCDM, The Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) is significantly suitable for ranking applications (Bilsel et al., 2006). The outranking method PROMETHEE brings together flexibility and simplicity for the user (Geldermann, Spengler, & Rentz, 2000) and is quite simple in conception and application compared to other methods for multicriteria analysis (Goumas & Lygerou, 2000). However, certain criteria from daily life can be expressed only with linguistic statements (Bilsel et al., 2006). The main difficulty arises in the estimation of the required input data that express qualitative observations and preferences. This information has to be interpreted and expressed quantitatively (Goumas & Lygerou, 2000). In spite of PROMETHEE MCDM method has a great deal of advantages, a disadvantage of the method is that evaluations, used as inputs in MCDM methods, often rely on opinions and experiences of decision makers and are expressed qualitatively, and, thus, are open to misinterpretation brought by the vagueness of linguistic terms. Therefore, the extension of the PROMETHEE method in fuzzy environment (Fuzzy PROMETHEE – F-PROMETHEE) is used in this study to ensure the right interpretation of valuable input data. The fuzzy PROMETHEE method is a combination of the PROMETHEE method and fuzzy number logic (Bilsel et al., 2006) and since it is the application of these approaches together as an integrated combination, we have to describe first the original PROMETHEE method briefly.

The PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) method is a multi-criteria decision making technique developed by Brans and Vincke (1985) and Brans, Vincke, and Mareschall (1986). It is well adapted to problems where a finite number of alternative actions are to be ranked considering several, sometimes conflicting, criteria (Goumas & Lygerou, 2000). Methodology is one of the most efficient as well as the most easy in the use of methodology among other methods employing in the application field. The PROMETHEE method has found a vast scope of application such as logistics and transportation (Iniestra & Gutiérrez, 2009; Mohamadabadi, Tichkowsky, & Kumar, 2009), environment management (Briggs, Kunsch, & Mareschal, 1990; Chou, Lin, & Lin, 2007), finance (Albadvi, Chaharsooghi, & Esfahanipour, 2007; Baourakis, Doumpos, Kalogeras, & Zopounidis, 2002), chemistry (Zhang, Ni, Churchill, & Kokot, 2006), production planning (Rekiek, de Lit, & Delchambre, 2002), energy management (Hyde, Maier, & Colby, 2003), service (D'Avignon & Mareschal, 1989; Du Bois, Brans, Cantraine, & Mareschal, 1989), and sport (Olson, 2001).

The implementation of PROMETHEE requires two additional types of information, namely: (1) information on the relative importance that is the weights of the criteria considered, (2) information on the decision-maker's preference function, which he/she uses when comparing the contribution of the alternatives in terms of each separate criterion (Dağdeviren, 2008). Constituting the data matrix of $A = (a, b, c, \ldots)$ alternatives evaluated by k criterias $c = (f_1, f_2, \ldots, f_k)$ with the weights of $w = (w_1, w_2, \ldots, w_k)$ is the first step of PROMETHEE method. The PROMETHEE method treats the multi-criteria problem appropriately like following type:

$$\max\{f_1(a), f_2(a), \ldots, f_n(a) | a \in A\} \tag{1}$$

where A denotes the finite set of possible alternatives, and f_j denotes n criteria to be maximized. $f_j(a)$ is an evaluation of this alternative for each alternative. PROMETHEE requests additional information. For each criterion a specific preference function must be defined. This function is used to compute the degree of preference associated to the best action in case of pairwise comparisons (Brans & Mareschal, 1998). When we compare two alternatives $a, b \in A$, we must be able to express the result of these comparisons in terms of preference. We, therefore, consider a preference function P (Dağdeviren, 2008). The preference function can have a value in the range of 0 to 1 and it is interpreting the difference in terms of a specific criterion between evaluations of such two alternatives as a and b. Let the preference function associated to the criterion $f_j(i)$ be

$$P_j(a \cdot b) = G_j[f_j(a) - f_j(b)] \tag{2}$$

$$0 \leqslant P_j(a, b) \leqslant 1 \tag{3}$$

where G_j is a non-decreasing function of the observed deviation (d) between $f_j(a)$ and $f_j(b)$. There are six basics types of preference functions proposed by Brans and Vincke (1985) with the aim of enabling the selection of specific preference function, which can be listed as usual function, U-shape function, V-shape function, level function, linear function and Gaussian function, and in each case no more than two parameters (threshold, q, p or s) have to fixed (Brans & Vincke, 1985; Wang & Yang, 2007).

Through the agency of the methodology provided by PROMETHEE method, the overall preference indexes for each alternative pair (4), the leaving flow ϕ^+ (5), the entering flow ϕ^- (6), and the net flow ϕ^{net} (7) are computed, by employment of the following equations,

$$\pi(a, b) = \frac{\sum_{i=1}^{k} w_i \times P_i(a, b)}{\sum_{i=i}^{k} w_i} \tag{4}$$

$$\phi^+(a) = \sum \pi(a, x), \quad x = (b, c, d, \ldots) \tag{5}$$

$$\phi^-(a) = \sum \pi(a, x), \quad x = (b, c, d, \ldots) \tag{6}$$

$$\phi^{net}(a) = \phi^+(a) - \phi^-(a), \quad x = (b, c, d, \ldots) \tag{7}$$

The leaving flow $\phi^+(a)$ is the measure of how a dominates all the other alternatives of A, where we assume that each alternative a is belonging to the set of A of alternatives. Symmetrically, the entering flow $\phi^-(a)$ gives that how a is dominated by all the other alternatives of A. ϕ^{net} represents a value function, whereby a higher value reflects a higher attractiveness of alternative a and is called net flow.

The PROMETHEE I partial ranking provides a ranking of alternatives (Brans & Vincke, 1985). The partial ranking is determined according to some computations about the preference situation of an alternative to another, the indifference of alternatives and incomparability of alternatives. Consequently, an alternative a is preferred to alternative b (8), alternative a and b are indifferent (9) or alternative a and b are incomparable (10) results are obtained

$$\begin{array}{lll} \phi^+(a) > \phi^+(b) & \text{and} & \phi^-(a) < \phi^-(b);\ \text{or} \\ \phi^+(a) > \phi^+(b) & \text{and} & \phi^-(a) = \phi^-(b);\ \text{or} \\ \phi^+(a) = \phi^+(b) & \text{and} & \phi^-(a) < \phi^-(b) \end{array} \tag{8}$$

$$\phi^+(a) = \phi^+(b) \quad \text{and} \quad \phi^-(a) = \phi^-(b) \tag{9}$$

$$\begin{array}{lll} \phi^+(a) > \phi^+(b) & \text{and} & \phi^-(a) > \phi^-(b);\ \text{or} \\ \phi^+(a) < \phi^+(b) & \text{and} & \phi^-(a) < \phi^-(b) \end{array} \tag{10}$$

Alternatives are ranked from the best to the worst one by using the net flow (ϕ^{net}) in PROMETHEE II complete ranking. Here, according to the comparments based on the net flows, the alternative with the higher net flow is assumed to be superior than the others, and the rest of the alternatives are ranked due to their net flow values likewise. Since PROMETHEE I does not provide a complete ranking, resulting ranking can not be compared with the ranking provided by PROMETHEE II. PROMETHEE I ensures creation of indifferent and incomparable alternatives. In some ranking problems, PROMETHEE I can give a complete ranking depending on the evaluation matrix values and, this ranking can not be different from the one achieved with PROMETHEE II (Brans & Vincke, 1985).

The PROMETHEE method is a relatively simple ranking method, which is perfectly intelligible for the decision maker and is accepted as one of the most intuitive MCDM methods (Balli, Karasulu, & Koruko ğlu, 2007). On the other hand, because of the vagueness and fuzzyness occurred when the input data used in the methodology is based on the decision makers' considerations and experiences and so expressed by linguistic terms, the probability of drawing a wrong conclusion by wrong assessments in the evaluation stages is considerably high. On the purpose of forestalling the problems can be caused by this vagueness, the Fuzzy PROMETHEE (F-PROMETHEE) method is developed, which is an integration of fuzzy numbers and PROMETHEE method. The F-PROMETHEE method is employed similarly to the PROMETHEE method, but only fuzzy number logic is included in the methodology of it solely.

In this study, the notation which presents a fuzzy number in the form of $x = (m, a, b)_{LR}$ and proposed by Dubois and Prade (1978) is followed. In this notation, the variable x belongs certainly to the fuzzy set; thus, its membership function $f(x)$ has the value 1. For values smaller than $(m - a)$ and larger than $(m - a)$, it does not belong to the set. For values in the interval $[m - a < x < m + b]$ its membership degree is given by the membership function that varies between 0 and 1. The letters L and R are used with the aim of indicating the change of the function $f(x)$ to the left and to the right of m, respectively. Following this notation a fuzzy number $x = (1, 0.1, 0.1)_{LR}$, under the assumption of linear L and R, is drawn in Fig. 1.

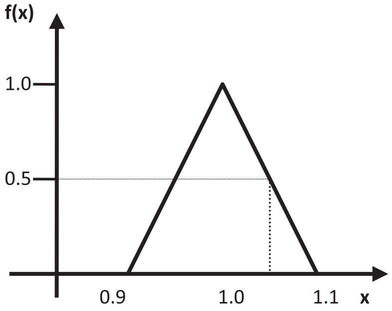

Fig. 1. Presentation of fuzzy number $x = (1, 0.1, 0.1)_{LR}$ when L and R are linear functions.

In this study, F-PROMETHEE method is employed as it is proposed by Goumas and Lygerou (2000) and Bilsel et al. (2006). Due to this all of the calculations and operations described in principles of PROMETHEE method previously will be executed with the fuzzy numbers, where the preference thresholds (q and p) and weights will remain as crisp numbers. Setting alternative evaluations as fuzzy numbers will help to translate qualitative information and vagueness in the decision maker's opinions to a solid mathematical expression (Bilsel et al., 2006). Preference threshold values q and p will be crisp numbers. If they were taken fuzzy, evaluation might be unclear due to the stretched form of a fuzzy number (Goumas & Lygerou, 2000). Also, criteria weights are not fuzzy; because PROMETHEE requires that the weights sum up to 1, they cannot be specified independently and cannot be specified as fuzzy (Bilsel et al., 2006).

In our study, the most frequently used preference function type in the literature and the most suitable preference function type to the characteristic of our problem, the linear preference function (type 5) with indifference and strict preference threshold values q and p, respectively is selected to employ (11)

$$
\begin{aligned}
&P(a,b) = 0 \quad \text{for } d \leqslant q \\
&P(a,b) = \frac{d-q}{p-q} \quad \text{for } q \leqslant d \leqslant p \\
&P(a,b) = 1 \quad \text{for } d \geqslant p
\end{aligned}
\tag{11}
$$

When we use F-PROMETHEE method, the d value showing the difference between the performances of a and b actions will be expressed as a (n, c, d) fuzzy number, and in such a case Eq. (11) will be change as follows;

$$
\begin{aligned}
&P(a,b) = 0 \quad \text{for } n-c \leqslant q \\
&P(a,b) = \frac{d-q}{p-q} \quad \text{for } q \leqslant n-c \quad \textit{and} \quad n+d \leqslant p \\
&P(a,b) = 1 \quad \text{for } n+d \geqslant p
\end{aligned}
\tag{12}
$$

It is necessary to have the basic knowledge of fuzzy numbers operations to be able to do the computations in the new equation obtained. Required formulas for basic operations with fuzzy numbers are presented at Table 1 (Goumas & Lygerou, 2000).

According to the application principles of PROMETHEE, it is proper to preference indices for single and multiple criteria must be placed in the interval [0, 1]. Therefore, the membership function of the fuzzy number $c\ (\alpha, \beta) = (m, c, d)$ is adjusted accordingly so that $m - c \geqslant 0$ and $m + d \leqslant 1$ (Goumas & Lygerou, 2000).

Eventually in F-PROMETHEE method, we can foresee from the introduced methodology that the results obtained will be fuzzy numbers, and according to come to a conclusion in our selection problem, these results of fuzzy numbers have to be ranked with respect to the principles of PROMETHEE method, and this means that fuzzy numbers have to be compared. In order to compare the fuzzy numbers, Goumas and Lygerou (2000) proposed to use Yager index (Yager, 1981), and we used this index to defuzzy the fuzzy numbers and compare them in this study. According to this method, defuzzy form of a given fuzzy number can be calculated as follows:

$$
F(m,a,b) = (3m - a + b)/3 \tag{13}
$$

The fuzzy number with the larger Yager index value will be considered bigger than the ones having smaller Yager index values (Bilsel et al., 2006). One after this the left steps are executed as how it is executed in PROMETHEE method, ϕ^{+}, ϕ^{-} and ϕ^{net} will be calculated as it is described previously.

Combination of fuzzy set theory and the PROMETHEE method was first proposed by Le Téno and Mareschal (1998). Goumas and Lygerou (2000) employed F-PROMETHEE method for the evaluation and ranking of alternative energy exploitation schemes of a low temperature geothermal field. Geldermann et al. (2000) conducted a Life Cycle Assessment (LCA) using F-PROMETHEE method in iron and steel industry in their study. In another study, Bilsel et al. (2006) synthesized both fuzzy and crisp data by using the Fuzzy PROMETHEE ranking method while they present a quality evaluation model for measuring the performance of hospital Web sites.

2.2. The zero–one goal programming method

As multi-criteria decision-making problems, for the evaluation and selection problems, a decision-making model is important to select an optimal solution from the proposed alternatives (Chang, Wey, & Tseng, 2009). In fact, the conflicts of resources and the incompleteness of available information make it almost impossible for decision makers to build a reliable mathematical model for representation of their preferences (Chang, 2007). In order to overcome this problem, many approaches are developed and many of the methodologies are applied. Among the proposed methodologies of multi-criteria decision making, goal programming (GP) is widely used (Lee & Kim, 2000).

Goal programming (GP), proposed by Charnes, Cooper, and Ferguson (1955), is most widely used approach within the multi-criteria decision-making (MCDM) (Patia, Vratb, & Kumarc, 2008). It

Table 1
Basic fuzzy operations.

Addition	$(m, a, b)_{LR} \oplus (n, c, d)_{LR} = (m + n, a + c, b + d)_{LR}$
Opposite	$-(m, a, b)_{LR} = (-m, a, \mathrm{b})_{RL}$
Subtraction	$(m, a, b)_{LR} - (n, c, d)_{LR} = (m - n, a + c, b + d)_{LR}$
Multiplication by scalar	$(m, a, b)_{LR} \times (n, 0, 0) = (mn, an, bn)$
Multiplication by fuzzy	
For $m > 0, n > 0$	$(m, a, b)_{LR} \otimes (n, c, d)_{LR} \approx (mn, cm + an, dm + bn)_{LR}$
For $m < 0, n > 0$	$(m, a, b)_{LR} \otimes (n, c, d)_{LR} \approx (mn, an - dm, bn - cm)_{RL}$
For $m < 0, n < 0$	$(m, a, b)_{LR} \otimes (n, c, d)_{LR} \approx (mn, -bn - dm, -\mathrm{an} - cm)_{RL}$
Inverse for $(m > 0)$	$(m, a, b)_{LR}^{-1} \approx (m^{-1}, bm^{-2}, am^{-2})_{RL}$

is designed to deal with the problems involving multiple conflicting objectives (Chang et al., 2009). In today's complex organisations the decision makers (DMs) do not try to maximize a well defined utility function. In fact the conflicts of interest and the incompleteness of available information make it almost impossible to build a reliable mathematical representation of the DMs' preferences. On the contrary, within this kind of decision environment the DMs try and achieve a set of goals (or targets) as closely as possible (Tamiz, Jones, & Romero, 1998).

The goal programming is an important technique for the decision-makers to solve multi-objectives decision making problems in finding a set of satisfying solutions (Chang, 2007) because it attempts to address simultaneously multiple objectives (Mathirajan & Ramanathan, 2007) and is more direct and flexible in manipulating different scenarios by adjusting either target values or weights (Leung & Chan, 2009). Most of the real-world problems are formulated into a single-objective linear programming (LP) methodology or the LP model (Leung & Chan, 2009). GP is a more powerful technique than linear programming (LP), since it can handle multiple objectives as well as a single objective (Kim & Emery, 2000). A goal programming model is useful in dealing with the multicriteria decision problems where the goals cannot simultaneously be optimized. GP allows decision makers to consider several objectives together in finding a set of acceptable solutions and to obtain an optimal compromise (Lee, Kang, & Chang, 2009). Basically, structures of GP and LP are the same (Leung & Chan, 2009). This model is a special extension of linear programming (Martel & Aouni, 1990). The concept of GP is to introduce extra auxiliary variables called deviations, which act not as 'decision-makers' but as 'facilitators' to formulate the model. These deviations represent the distance between aspiration levels of goals (target values) and the realized results (Leung & Chan, 2009). The major difference between LP and GP is that the GP model does not optimize (maximize/minimize) the objective directly, as in the case of LP. Instead, it attempts to minimize the deviations (Kim & Emery, 2000).

A key element of a GP model is the achievement function that measures the degree of minimization of the unwanted deviation variables of the goals considered in the model (Demirtaş & Üstün, 2009). As a course of its nature, while GP attempts to combine the logic of optimization in mathematical programming with the decision maker's desire to satisfy several goals (Patia et al., 2008), there can be a need for system constraints to be only one or zero, representing that if the alternative is selected or not, in selection problems. When there is such a need in the examining case, zero–one goal programming (ZOGP) technique can be used to aid in the decision making process to generate a reliable and optimal solution. ZOGP permits the consideration of resource limitations and the other selection limitations that must be rigidly observed in selection problems. ZOGP also permits the ranked inclusions of alternatives so the selection is based (Lee & Kim, 2000).

ZOGP is a kind of GP methodologies, in which the decision variable values can be result in only one ore zero. By utilizing these deviational variables, the general ZOGP model can be illustrated as follows:

$$\begin{aligned} \min \quad & \sum WP_j[d_i^+ + d_i^-] \\ \text{s.t.} \quad & \sum[A_{ij}X_{ij}] - d_i^+ + d_i^- = B_i \\ & X_{ij} = 0, \ \text{if } x_{ij} \text{ is not selected} \\ & 1, \ \text{if } x_{ij} \text{ is selected} \end{aligned} \tag{14}$$

Deviational variables can be positive or negative. A positive deviation variable (d^+) represents overachievement of the goal. A negative deviation variable (d^-) represents underachievement of the goal (Kim & Emery, 2000). The objective function, given above will attempt to minimize the sum of the deviations present in each of the constraint equations. The goals will be preemptive in nature; as a result, priorities will be attached to each of the goals (Badri, 1999). Each type of achievement function leads to a different GP variant (Demirtaş & Üstün, 2009). Also, the goals representing by achievement functions must be prioritized in a hierarchy of importance (Kim & Emery, 2000). GP models can be classified into two major subsets. In the first type the unwanted deviations are assigned weights according to their relative importance to the DM and minimized as an Archimedian sum. This is known as weighted GP (WGP) (Tamiz et al., 1998) and general mathematical model corresponding to WGP is as follows:

$$\begin{aligned} \min \quad & z = \sum_{i=1}^{k} (u_i n_i + v_i p_i) \\ \text{s.t.} \quad & f_i(x) + n_i - p_i = b_i, \quad i = 1, \ldots, Q, \ x \in C_g \end{aligned} \tag{15}$$

In the other major subset of GP the deviational variables are assigned into a number of priority levels and minimized in a lexicographic sense. A lexicographic minimization being reached by all higher priority level minimizations. This is known as lexicographic GP (LGP), and its algebraic representation is as follows (Tamiz et al., 1998):

$$\begin{aligned} \text{Lex min} \quad & a = (g_1(n,p), g_2(n,p), \ldots, g_L(n,p)) \\ \text{s.t.} \quad & f_i(n,p), + n_i - p_i = b_i, \quad i = 1, \ldots, Q \end{aligned} \tag{16}$$

According to the study conducted by Tamiz et al. (1998), around 64% of GP applications reported in the literature use LGP and 21% WGP.

GP model consists of two sets of constraints – system constraints and goal constraints. System constraints are formulated following the concept of LP, while goal constraints are auxiliary constraints, which determine the best possible solution with respect to a set of desired goals (Leung & Chan, 2009). In ZOGP models, the decision variables for the selection procedure are zero–one variables (Kim & Emery, 2000).

The advantage of GP is that it can be solved using conventional (single objective) optimization software (Mathirajan & Ramanathan, 2007). With the fast growth in computational facilities, both linear and non-linear GP can be solved, using well-developed software, such as linear interactive and discrete optimization (LINDO) (Leung & Chan, 2009). In order to generate zero–one solutions for the selection procedure in ZOGP, it is proper to use zero–one GP computer support software. (Kim & Emery, 2000). But the problem we are studying does not need a special computer software for ZOGP method, for this reason a regular GP computer software will be used in our application.

Some recent studies in the literature considering ZOGP can be listed briefly as follows. Chang et al. (2009) solved a real-world, multi-criteria, revitalization strategies project selection problem for the historic Alishan Forest Railway in Taiwan by using fuzzy Delphi, ANP and ZOGP in their study. Suggested the methodology uses an integrated approach and reflects the interdependencies between the evaluation criteria and candidate projects. Mathirajan and Ramanathan (2007) modeled the tour scheduling problem of the marketing executive using ZOGP (GP). The ZOGP model is solved using LINDO software package. In another study, Wey and Wu (2007) suggested an improved transportation infrastructure (TI) project selection methodology to be able to introduce a method of solution through a real-world TI empirical example on an ongoing decision-making project in Taichung City, Taiwan, which reflects the interdependencies among evaluation criteria and candidate projects using ANP within a ZOGP model. In order to provide a systematic approach to set priorities among multi-criteria and trade-off among objectives, ANP is suggested to be applied prior to GP formulation. As another example, Karsak, Sozer, and Alptekin (2002) presented in their study about product planning in QFD a zero–one goal programming methodology that includes importance levels of PTRs derived using the ANP, cost budget, extendibility level and manufacturability level goals to determine the PTRs to be considered in designing the product. Dağdeviren and Eren (2001) presented AHP and general structure of ZOGP techniques and an application to select supplier is performed using the two methods. Using the two methods together is also discussed in this study. Lee and Kim (2000) suggested an improved IS project selection methodology which reflect the interdependencies among evaluation criteria and candidate projects using ANP within a ZOGP model. Kim and Emery (2000) studied a project selection and resource planning problem and developed a ZOGP model to determine which programs to pursue in an effort to maximize profit over a four-year period, develop machine procurement plans and estimate personnel requirements.

3. Proposed F-PROMETHEE – ZOGP integrated approach

Proposed integrated approach, composed of F-PROMETHEE and ZOGP methods, for the equipment selection problem consists of four basic stages: (1) data gathering, (2) F-PROMETHEE computations, (3) ZOGP computations, and (4) decision making. In the first stage, alternative equipments and the criteria which will be used in their evaluation are determined and weights belonging to each criteria are setted. In our study, weights are assigned according to the experiences and considerations of decision maker team. Multi-criteria decision making methods like AHP and so on could be used for this aim, depending on the structure of the selection problem and views of the decision making team.

Equipment priorities are found by using F-PROMETHEE computations in the second stage. Firstly, preference functions and parameters are determined by the decision making team. After the approval of the functions, partial ranking with F-PROMETHEE I and complete ranking with F-PROMETHEE II are determined.

After the net flows are computed with F-PROMETHEE II and they are defuzzied with Yager index as previously explained, in the third stage ZOGP model is constructed for the equipment selection problem as first step. Net flows computed and defuzzied are normalized and then added to the ZOGP model as a constraint. Then in the last step of this stage, ZOGP model is solved with LINDO/PC Version 6.1, LINDO Systems, Inc., copyright © 2002.

In the last stage of results of two methods are compared in the base of determined goals for our selection problem. Considering this comparment, the best equipment is selected according to the rankings with the integrated approach proposed by F-PROMETHEE I and II and ZOGP methods. Schematic representation of the proposed approach is presented in Fig. 2.

4. Numerical application of proposed approach

Welding machine is an important equipment used commonly for various sectors. There is a wide diversity in the alternative welding machine models of this kind of equipment. In our application, MIG/MAG welding machine selection of the company input datas belong to will be done by employing the F-PROMETHEE and ZOGP methods respectively according to our proposed integrated approach. The company wants to select the welding machines due to such targets as maximizing the sectoral usability, providing maximum working conformity, providing being available to maximum ranged item variety, and in addition to these optimizing the ergonomically conformity.

4.1. Data gathering

At first step, a decision making team consisting of company officials and academists as analyzers, is formed. Afterwards, 11 alternative welding machines took place in the evaluation process. At third step, seven criteria which will be used to compare the possible alternatives are determined by the decision making team. Then, next step, the experts in the decision making team are given the task of assigning weights for each criteria, in the base of their experiences and knowledge about this subject and the benefits of the company.

4.2. F-PROMETHEE calculations

In this stage, with the purpose of preventing the wrong assessment probability emerging from the vagueness and ambiguity caused from linguistic terms in the input datas constituted standing on decision makers' considerations and experiences, a different solution for equipment selection problems with the F-PROMETHEE (F-PROMETHEE) method using fuzzy input datas and benefiting from fuzzy set theory will be introduced.

Firstly the criterias including linguistic evaluation terms are determined for 11 alternative equipments. There are four criterias with vagueness of linguistic expressions, while the alternatives are evaluated based on the whole seven criterias, hence preliminarily with F-PROMETHEE method they will be examined. These criterias determined by decision making team are sectoral usability, working conformity, conformity to handling the wire diameter variations (handling range), and ergonomic suitability.

In our application, the decision maker has six evaluation choice, each is standing for a different triangular number for linguistic terms. These can be listed as VB: Very Bad $(0, 0, 0.15)_{LR}$; B: Bad $(0.15, 0.15, 0.15)_{LR}$; W: Weak $(0.30, 0.15, 0.20)_{LR}$; M: Medium $(0.50, 0.20, 0.15)_{LR}$; G: Good $(0.65, 0.15, 0.15)_{LR}$; VG: Very Good $(0.80, 0.5, 0.20)_{LR}$; E: Excellent $(1, 0.20, 0)_{LR}$ (Bilsel et al., 2006). These cited fuzzy numbers are given in Fig. 3 and the evaluation matrix constituted using these fuzzy numbers is given in Table 2. Weights of criteria are determined by decision making team as introduced before, and are equal for each criteria in this application.

Next step, F-PROMETHEE method is employed as it was introduced at Section 2. Linear preference function is selected for the evaluation. The threshold values q and p defined for this application are set as zero and 0.60, respectively (Bilsel et al., 2006; Goumas & Lygerou, 2000). After the evaluation matrix and the preference function are determined, alternative equipments are evaluated, and positive flow (ϕ^{+}), negative flow (ϕ^{-}) and net flow (ϕ^{net}) values are calculated and then defuzzied as it is introduced in Section 2. Obtained flow values are presented in Table 3, and with the usage of net flow values given in this table calculated F-PROMETHEE II complete ranking to identify the best alternative and the accurate ranking of alternatives is presented in Fig. 4.

Taking into account the preference of each criterion and the vagueness of the input datas, Alternative 3 is selected to be the best alternative welding machine according to the F-PROMETHEE II complete ranking results, and the other alternatives are ranked in the order of A7, A9, A5, A10, A4, A1, A11, A6, A2 and A8. As next stage, calculated net flows will be normalized and appended to the ZOGP model, which will be constructed for the evaluation of the criterias can be numerically expressed by the decision makers.

4.3. ZOGP calculations

Goal programming is designed to deal with the problems involving multiple conflicting objectives. However, to overcome the drawback of GP, decision makers must specify the goals and

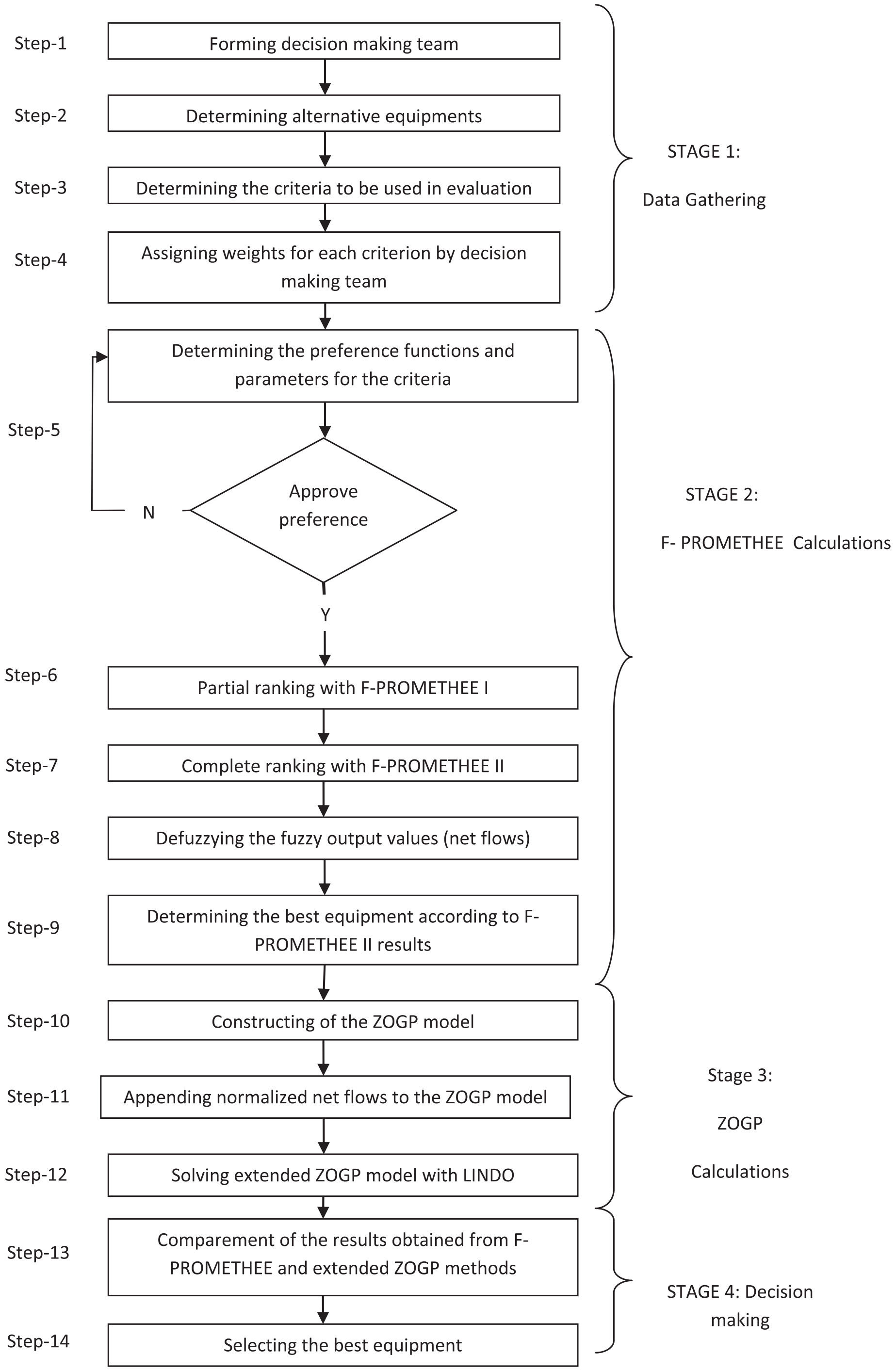

Fig. 2. Schematic representation of the approach proposed for equipment selection.

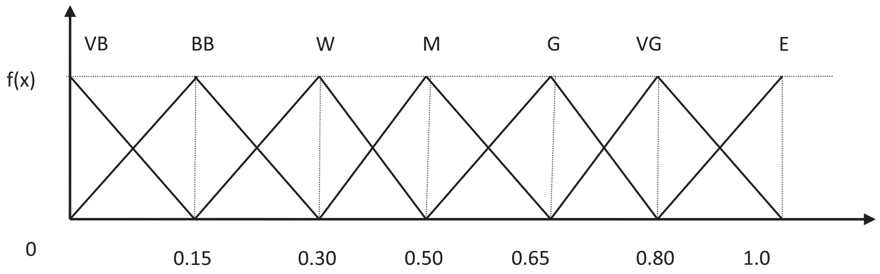

Fig. 3. Fuzzy numbers used in application.

Table 2
Evaluation table constituted for fuzzy expressions.

Criteria	Sectoral usability	Working conformity	Handling range	Ergonomic suitability
Max/min	Max	Max	Max	Max
Weights	0.25	0.25	0.25	0.25
A1	G	W	W	E
A2	W	G	VB	W
A3	E	E	G	G
A4	E	VG	B	M
A5	G	G	G	G
A6	W	G	VB	M
A7	VG	E	E	W
A8	G	W	W	B
A9	VG	E	E	W
A10	VG	E	W	M
A11	G	W	W	VG

Table 3
F-PROMETHEE flows.

Alternatifler	ϕ^+	ϕ^-	ϕ^{net}
A1	2.185	2.124	0.061
A2	0.600	2.955	−2.355
A3	3.864	0.285	3.579
A4	0.891	0.800	0.091
A5	2.027	0.852	1.175
A6	0.445	2.759	−2.314
A7	2.474	0.400	2.074
A8	0.578	3.259	−2.681
A9	2.374	0.511	1.836
A10	1.174	0.911	0.263
A11	0.568	2.124	−1.556

their priorities a priori (Wey & Wu, 2007). This drawback is even more evident when both tangible and intangible factors need to be considered, when interdependent factors are involved, and when a number of people need to participate in judgement (Chang et al., 2009). To be able to overcome this problem, normalized values of net flows calculated with F-PROMETHEE method are applied into the ZOGP model to set the priorities for possible alternatives.

In this application, the company we are doing the equipment selection for, is seeking for the best equipment with the most suitable price for the most component properties it will have. The company has the alternatives evaluation values based on the constraints can be expressed, assessed and compared numerically. The criteria and assessments belonging these criteria and the alternative equipments values are presented hereunder in Table 4.

Company has some limited values for the constraints of the model. Because of the financial restrictions and budget plans, the company can allocate maximum 15,000 TL (Turkish Liras) for the selection of equipments. Furthermore, due to the lifting and transporting capability of a transporting vehicle, maximum value of weight of an alternative welding machine can be 750 kilos, and because of the limited place in the plant volume of an equipment can have the maximum value of 10,000 m^3.

The constructed ZOGP model with the relevant constraints and parameters is as follows:

$$\min z \quad P_1(d_1^+) + P_2(d_2^+) + P_3(d_3^+) + P_4(d_4^-) + P_4(d_4^+) \tag{17}$$

Subject to

$$1652x_1 + 1770x_2 + 2478x_3 + 4307x_4 + 1810x_6 + 3569x_7 + 1855x_8 + 4130x_9 + 2200x_{10} + 2517x_{11} + d_1^- - d_1^+ = 15000 \tag{18}$$

$$100x_1 + 85x_2 + 101x_3 + 148x_4 + 120x_5 + 95x_6 + 133x_7 + 190x_8 + 144x_9 + 136x_{10} + 87x_{11} + d_2^- - d_2^+ = 750 \tag{19}$$

$$1666x_1 + 3478x_2 + 2880x_3 + 54608x_4 + 28808x_5 + 1690x_6 + 4437x_7 + 1500x_8 + 4530x_9 + 4570x_{10} + 22552x_{11} + d_3^- - d_3^+ = 10000 \tag{20}$$

$$0.355x_1 - 13.613x_2 + 20.688x_3 + 0.526x_4 + 6.792x_5 - 13.376x_6 + 11.988x_7 - 15.497x_8 + 10.613x_9 - 1.520x_{10} - 8.994x_{11} + d_4^- - d_4^+ = 1 \tag{21}$$

$$x_i = 0 \text{ or } 1 \quad i = 1, 2, \ldots, 11 \tag{22}$$

$$d_i^-, d_i^+ \geqslant 0, \quad i = 1, 2, 3, 4 \tag{23}$$

In the model presented above, it can be seen that the information obtained from F-PROMETHEE II ranking (normalized net flows) is appended in our extended ZOGP model as a goal. Model is formed from three goals determined by decision making team; minimizing cost goal (18), minimizing weight goal (19), minimizing volume goal (20), and the adjunct normalized net flow value goal (21). The last two constraints are non-negativity constraints for main (22) and auxiliary variables (23). We preferred a Weighted ZOGP model to solve our problem, because it is seeking to minimize the total deviation of the determined goals by decision making team. Hence, this model is able to consider all of the goals simultaneously by forming an achievement function that minimized the total weighted deviation from all the goals stated in the model (17). In

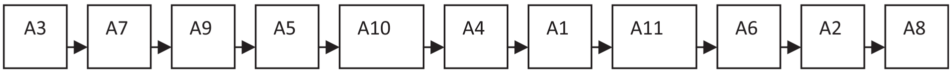

Fig. 4. F-PROMETHEE II complete ranking.

Table 4
Values used for assessment corresponding to the construction of the ZOGP model.

	Weight	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11
Cost of the equipment	0.25	1652	1770	2478	4307	2124	1810	3569	1855	4130	2200	2517
Weight of the equipment	0.25	100	85	101	148	120	95	133	290	144	136	87
Volume of the equipment	0.25	1666	3478	2880	5460	2808	1690	4437	10	4930	4570	2252
Normalized net flow values of F-PROMETHEE II	0.25	0.355	−13.613	20.688	0.526	6.792	−13.376	11.988	−15.495	10.613	1.520	−8.994

Table 5
Result comparments of the used methods.

Resources	RHS values	ZOGP results		F-PROMETHEE results	
		Achieved values	Deviation values	Achieved values	Deviation values
Cost	15,000	5959	9041	6047	8953
Weight	750	248	502	234	516
Volume	10,000	7126	2874	7317	2683

this application, the decision making team setted the weights of goals equally, because their preference regarding the relative importance of each goal does not differ from each other, this means, all of the goals targeted have equivalent importance for the benefit of the company.

Proposed ZOGP model is solved with LINDO/PC Version 6.1, LINDO Systems, Inc., copyright © 2002, and to be able to select the best equipment alternative while meeting the existing constraints. According to the proposed ZOGP model, alternatives selected to be purchased are Alternative 1 and Alternative 4. The two initial alternatives from the complete ranking of F-PROMETHEE are Alternative 3 and Alternative 7, however, the obtained results of these two conditions are compared in Table 5.

If the results of both methods will be examined, it can be seen that all of the deviation values are positive. However, if we examine these positive deviation values, we can see that, the equipments selected best whose results gained with the method which has more positive deviation values are most suitable and serves more for the benefits of the company. In conclusion, our proposed integrated F-PROMETHEE and ZOGP approach is a more efficient technique in this kind of equipment selection problems, with regards to the results obtained.

5. Conclusions

In this paper, an integrated approach for equipment selection is proposed. Two different methods, F-PROMETHEE and ZOGP, and then proposed combined approach are introduced respectively. Alternative equipments and the set of criteria are determined according to the views of the decision making team, and the weights for the criteria in F-PROMETHEE method and the goals in ZOGP method are assigned with regards to decision making team's experiences and conviction. Our combined F-PROMETHEE and ZOGP approach endeavors to minimize the overall deviations in the objective function given the various goals and objectives. F-PROMETHEE method is used to deal with the fuzziness of the input data. Subsequently, a ZOGP model regarding the F-PROMETHEE II results as a constraint is developed, with the aim of selecting the best alternative according to conflicting criteria, from the set of possible alternatives. Results gained from F-PROMETHEE method and our proposed approach are compared and it is seen that each method does not give the same solutions.

With this study, we indicated the effect of the linguistic terms, that is to say fuzziness to the decision making process, and developed a new approach that is taking account the fuzziness and vagueness of input datas. A more realistic and more appropriate to the criteria and preferences determined by decision making team ranking is achieved with usage of fuzzy numbers as input datas. In the other words, in the case of existing of linguistic datas in the evaluation process it is seen that fuzzy assessment brings a more suitable and logical solution to the problem. This study has illustrated how the F-PROMETHEE results can be integrated and combined in a ZOGP model to include the preferences of decision maker and vagueness of input datas in the equipment selection decision process.

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