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FUZZY MULTIPLE OBJECTIVE DECISION MAKING IN THE CONSTRUCTION INDUSTRY

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ABSTRACT

Business decisions relate to future events. They influence the future business success of an organisation. Business decisions must be continuously revised. The model of multiple objective decision making, based on fuzzy logic, seems to apply when continuous business decision making revisions are used.

The linear mathematical formulation of multiple objective decision making of Lai might be implemented in a decision making process in the construction industry. That is the fuzzy parameters of linear programming are modeled by preference-based membership functions. These functions represent subjective degrees of satisfaction or, degree of optimalities or feasibilities within given tolerance. The membership functions are similar to utility functions. They are determined by subjective judgment.

This paper deals with Lai's model of multiple objective decision making. The first part of the paper explains the modified version of the model itself to construction industry circumstances. The second part gives an example that illustrates the improvement of business decision making when it is supported by computer technology.

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INTRODUCTION

The linear mathematical formulation of multiple objective decision making presented by crisp (nonfuzzy) values has been studied by many authors /14/, /8/, /4/, /6/, /11/, /3/, /10/. Zimmermann offered the solution for the formulation by fuzzy linear programming /14/. His solution was improved by Chuang, Munro, Lloyd Smith /4/. Lai's iteractive multiple objective system technique contributed to the improvement of flexibility and robustness of multiple objective decision making methodology /8/. Lai considered several characteristic cases with which a business decision maker may encounter in his practice. The cases could be defined as nonfuzzy and fuzzy cases.

The aim of this paper is to point to problems related to the construction industry that are presented by fuzzy variables. Construction industry characteristics are mobility of the assets and the work force. The assets, such as civil engineering machines, can be used for several building sites. The design to move a machine from one construction site to another is a fuzzy decision. Frequent revisions of such decision are a day-to-day necessity. The infrequent revision may negatively affect the future business success with a long-term negative consequence. Under the circumstances of contemporary dynamic environmental challenges the emphasis is on the effectiveness of the decision maker's subjective judgments. Such effectiveness can be increased as a result of the high quality of analytic information supplied by numerical calculation. Moreover, when computers support the decision makers, their problem solving can be significantly improved.

The first part of this paper deals with the nonfuzzy multiple objective model solved by different fuzzy approaches. These approaches are, in fact, the gradual improvements to the optimal solution of the model. That is the solution of:

* Zimmermann based on Bellman-Zadeh's principle of decision making in a fuzzy environment
* Chuang, Munro and Lloyd Smith, and
* the authors of this paper.

The second part of the paper gives the modified version of Lai's fuzzy multiple objective model to solve some decision problems in the construction industry. It is based on the nonfuzzy multiple objective model. It presents the theoretical foundation to the improvement of business decision making supported by computer.

NONFUZZY MULTIOBJECTIVE PROBLEM

The problem of multiobjective optimization written in a linear programming form is:

Find a vector **x** written in the transformed form

$$x^T=[x_1, x_2, \ldots, x_n]$$

which maximizes objective functions

$$\max z_i=\sum_{j=1}^{n} c_{ij}x_j, \qquad j=1,2,\ldots,n \tag{1}$$

with constraints

$$\sum_{j=1}^{n} a_{ij}x_j \leq b_i \qquad i=1,2,\ldots,m$$

$$x_j \geq 0 \qquad j=1,2,\ldots,n \tag{2}$$

where c_{ij}, a_{ij} and b_i are crisp (nonfuzzy) values. This problem has been studied and solved by many authors. Zimmermann /14/ has solved this problem by using the fuzzy linear programming. He formulated the auxiliary fuzzy linear program in the following way:

Find separately for every objective function z_i, its maximum z_j^+ and minimum value z_j^- by solving

$$z_i^+ = \max z_i = \sum_{j=1}^{n} c_{ij}x_j \quad \text{and} \quad z_i^- = \min z_i = \sum_{j=1}^{n} c_{ij}x_j \tag{3}$$

with constraints (2).

Solutions z_i^+ and z_i^- are known as individual best and worst solutions respectively.

Since for the every objective function z_i, its value changes linearly from z_i^- to z_i^+ it may be considered as a fuzzy number with the membership function $\mu_i(z_i)$ that is shown in Figure 1.

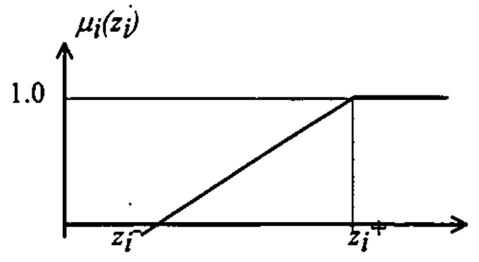

Figure 1. Objective function as a fuzzy number

$$\mu_j(z_j) = \begin{cases} 0 & \text{for } z_j \leq z_j^- \\ (z_j - z_j^-)/(z_j^+ - z_j^-) & \text{for } z_j^- \leq z_j^+, \quad j = 1,2,\ldots,k \\ 1 & \text{for } z_j \geq z_j^+ \end{cases} \tag{4}$$

According to Bellman-Zadeh 's principle of decision making in the fuzzy environment the grade of membership of a decision g, specified by objectives z_j, is obtained by /1/:

$$\gamma = \min \mu_j(z_j), \quad j=1,2,\ldots,k \tag{5}$$

or

$$\gamma \leq \mu_j(z_j), \; j=1,2,\ldots,k \tag{6}$$
$$0 \leq \Upsilon \leq 1$$

According to this principle the optimal values of multicriteria optimization correspond to maximum value of g. The auxiliary linear programme is obtained by:

$$\bar{z} = \max \gamma \tag{7}$$

with constraints (6) , taking into account (1) and (4)

$$-\sum_{j=1}^{n} c_{ij} + (z_i^{+} - z_i^{-})\,\gamma \le -z_i^{-} \qquad i=1,2,\ldots,k$$

$$0 \le \gamma \le 1, \; x_j \ge 0 \qquad j=1,2,\ldots,n \tag{8}$$

The original linear constraints (2) are added to these constraints.

Lai has proposed the auxiliary objective function in the form /8/:

$$\bar{z} = \max\,[\delta \sum_{i=1}^{k} w_i\, \mu_i\,(z_i)\gamma]$$

which can be transformed into the augmented objective function by substituting $\mu_j(z_j)$ with the corresponding value from expression (1) and (4).

$$\bar{z} = \max[\,\delta \sum_{i=1}^{k} w_i \sum_{j=i}^{n} c_{ij} x_j + \gamma] \tag{9}$$

where δ has to be chosen as a small positive number ($0 < \delta \le 1$) while w_i are weighting coefficients that represent relative importance of the objective functions z_i. These coefficients have to be chosen to satisfy:

$$\sum_{i=1}^{k} w_i = 1 \tag{10}$$

The coefficient γ represents the degree of acceptability or degree of possibility obtained from the optimal solution. For some specific problems, as it is proposed by Chuang, Munro and Lloyd Smith /4/ the minimal value of the coefficient γ_l can be prescribed. The authors of this paper, apart of the lower value, prescribe the upper value of the coefficient γ_n. Hence two new constraints are added in this linear programme:

$$\gamma \ge \gamma_l \qquad \gamma \le \gamma_u \tag{11}$$

where

$$0 \le \gamma \le 1 \qquad 0 \le \gamma,$$

The solution of the auxiliary linear programme with one objective function (9) and constraints (2), (8) and (11) is in fact the optimal solutions of the multiobjective problem (1) and (2) by the modified Zimmermann's procedure.

Coefficients of satisfaction in relation to the best individual solutions z_i^{+} are

$$\alpha_i = \frac{\max z_i}{z_i^{+}} \qquad i=1,2,\ldots,k. \tag{12}$$

FUZZY MULTIOBJECTIVE PROBLEM

The multiobjective fuzzy optimization was studied by Lai and Hwang /8/, /7/, /5/. Lai develops the interactive multiple objective system technique - IMOST - to improve the flexibility and robustness of multiple objective decision making methodologies. He observes several characteristic cases with which a business decision maker may be encountered in his practice. First problem is the problem of the nonfuzzy multiobjective optimization. The other problems include fuzzy goals, fuzzy objectives, fuzzy resources and technological coefficients. All these cases are mutually interrelated, and the corresponding computer programme is developed to help a decision maker to find the optimal solution.

Let us face the problem with fuzzy goals and fuzzy values b_i that a decision maker is faced in the construction industry.

Find a vector **x** written in the transformed from:

$$x^T=[x_1, x_2, \dots, x_n]$$

to maximize the objectives functions z_i

$$z_i=\sum_{j=1}^{n} c_{ij}x_j \,(>,\approx)\, z_i^0, \quad i=1,2,\dots,k. \tag{13}$$

with fuzzy constraints

$$g_i(x)=\sum_{j=1}^{n} a_{ij}x_j(<,\approx)b_i, \quad i=1,2,\dots m \tag{14}$$

where z_i^0 $(i=1,2,\dots,k)$ are the goals of the objectives, and signs $(>,\approx)$ and $(<,\approx)$ denote fuzzy inequalities. The values of objective functions z_i are fuzzy numbers with membership functions shown in Figure 2.

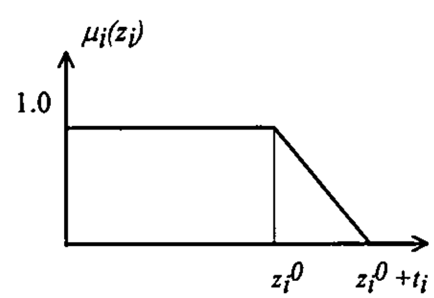

Figure 2. Membership functions for objective z_i

These functions are

$$\mu_i(z_i)=\begin{cases} 1 & \text{for } z_i \le z_i^0 \\ 1-(z_i^0-z_i)/t_i & \text{for } z_i^0 \le z_i \le z_i^0+t_i, \quad i=1,2,\dots,k \\ 0 & \text{for } z_i \ge z_i^0 \end{cases} \tag{15}$$

The values t_i are tolerances of the goal values z_i^0 and they have to be

$$t_i \le (z_i^0-z_i^-), \quad i=1,2,\dots,k$$

According to the Figure 3. the membership functions $\mu_i(g_i)$ are

$$\mu_i(g_i)=\begin{cases} 0 & \text{for } g_i \le b_i \\ 1-(g_i-b_i)/d_i & \text{for } b_i \le g_i \le b_i+d_i, \quad i=1,2,\dots,m \\ 1 & \text{for } g_i \ge b_i+d_i \end{cases} \tag{16}$$

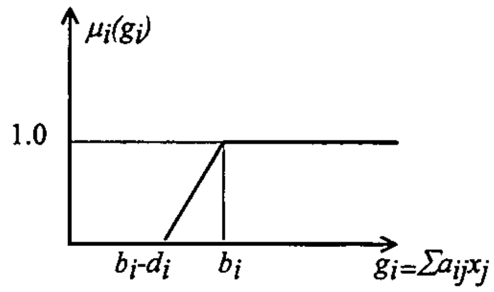

Figure 3. Membership functions for constraints g_i

If we apply Bellman-Zadeh's principle in the same way as in the previous section, the new objective function and constraints (15) and (16) may be written as:

$$\bar{z} = \max \left[\delta \sum_{i=1}^{k} w_i \sum_{j=1}^{n} a_{ij}\, x_j + \gamma\right] \tag{17}$$

with constraints

$$-\sum_{j=1}^{n} c_{ij}x_j + t_i\gamma \le -z_i^0 + t_i, \quad i=1,2,....k$$

$$\sum_{j=1}^{n} a_{ij}x_j + d_i\gamma \le b_i + d_i, \quad i=1,2,...,m \tag{18}$$

$$\gamma \ge \gamma_l, \quad \gamma \le \gamma_u, \quad x_j \ge 0, \quad j=1,2,.....,n$$

The optimal values of variables x_j $(j=1,2,..,n)$ are obtained by solving this linear programme. According to expressions (13) the corresponding maximal values of objective function max z_i are calculated. The coefficients of satisfaction α_l in relation to the individual best solutions z_i^+ $(i=1,2,...,k)$ may be determined in relation to (12).

Lai formulates the objective function (17) in the form /8/:

$$\bar{z} = \max \delta\left[\sum_{i=1}^{k} w_i\mu_i(z_i) + \sum_{i=1}^{m} q_i\mu_i(g_i) + \gamma\right] \tag{19}$$

where

$$\sum_{i=1}^{k} w_i + \sum_{i=1}^{m} q_i = 1$$

The coefficients w_i and q_i are weighting coefficients that determine the relative importance of the constraints.

In the case when

* the fuzzy goals z_i^0 are not given
* the objective functions z_i are not given

the z_i^* may be assumed as a goal z_i^0 and $(z_i^+ - z_i^-)$ as a tolerance t_i. In this case, the first group of constraints (18) becomes identical to constraints (8)

$$- \sum_{j=1}^{k} c_{ij}x_j + (z_j^+ - z_j^-)\,\gamma \leq - z_j\,,\; j=1,2,.....,k$$

According to this procedure the computer programme has been written in FORTRAN 77 programming language.

Input data are:

- number of objectives k
- number of constraints m
- number of unknowns n
- goals z_i $(i=1,2,..,k)$,
- elements c_{ij} $(i=1,2,..,k; j=1,2,...,n)$
  a_{ij} $(i=1,2,..,n)$
  b_i $(i=1,2,..,m)$
- tolerances t_i $(i=1,2...,k)$ and
  d_i $(i=1,2,...,m)$

The programme determines the individual best z_i^+ solution and the individual worst solution z_i^- for every objective i $(i=1,2,...,k)$. The objective functions are (3) and the constraints are (2). The obtained values z_j^+ and z_j^-, based on the modified Zimmermann's procedure, are used to solve the linear programme with the objective function (9) and constraints (2), (8) and (11). For the nonfuzzy problem, this programme gives the values of unknown x_j $(j=1,2,..,n)$, maximal values of objective function z_i $(i=1,2,...,k)$, coefficient of acceptability γ and coefficients of satisfaction α_i $(i=1,2,..,k)$. For the fuzzy problem, the linear programme with the objective function (17) and the constraints (18) gives: the optimal value of unknown x_i $(i=1,2,...,n)$, objective function z_i, coefficients of satisfaction α_i (i=1,2,..,k) and coefficient of acceptability γ.

EXAMPLE

The construction firm A produces, transports and places concrete on a building site. Fresh concrete is produced at a central concrete plant and transported by seven transit mixers over the distance 1500-3000 m to three building sites. Three concrete pumps and eleven interior vibrators are used for delivering, placing and consolidating the concrete at each building site (BS).

Working capacities are:

- central concrete plant 60 m^3/h, weekly 2520m^3 with tolerance 200 m^3,
- transit mixers for building site
  - BS1 8.45 m^3/h
  - BS2 9.26 m^3/h
  - BS3 7.26 m^3/h
- concrete pumps:
  - 16 m^3/h at BS1
  - 22 m^3/h at BS2
  - 26 m^3/h at BS3
- interior vibrators 4.0 m^3/h

Required working power:

- 5 workers for central concrete plant
- 7 workers (drivers) for transit mixers
- 6 workers for concrete pumps
- 22 workers for delivering, placing and consolidating of concrete at building sites (6 for BS1+ 7 for BS2+ 9 for BS3).

Minimal required quanitities of concrete are:

- for BS1 14.0 m^3/h or 588 m^3 per week with tolerance 47 m^3
- for BS2 18.0m^3/h or 756 m^3 per week with tolerance 60 m^3
- for BS3 21.5 m^3/h or 903 m^3 per week with tolerance 72m^3.

These values are calculated for 42 working hours per week.

The expected profit per 1m^3, as the **first objective**, is:

- at BS1 12$
- at BS2 10$
- at BS3 11$.

The minimal expected weekly profit as a fuzzy value is z^0= 27000$ per week with tolerance t_1=2100 $.

The index of quality at building sites, as the **second objective**, is ranged from 5 points/m^3 (bad) quality to 10 points /m^3 (excellent) quality. For

- BS1 its value is 9
- BS2 its value is 10
- BS3 its value is 7.5

The minimal expected total weekly number of points for quality, as fuzzy value, is $z^0{}_2$=21400 with tolerance t_2= 1700 points.

The index of worker satisfaction, that depends on the working and other conditions, as the **third objective**, is also ranged from 5 to 10 points per m^3 of produced, transported and placed concrete. Its values are

- 8 points at BS1,
- 7 points at BS2
- 9 points at BS3

The minimal expected total weekly number of points as a fuzzy value is z^0=18000 with tolerance t_3=1400.

Weighting numbers that represent the relative importance of these objectives are:

- for profit w_1=0.40
- for quality w_2= 0.40
- for worker satisfaction w_3= 0.20.

Find:

* ***the optimal value of unknowns x_i (i=1,2,3) that represent quantities of concrete which have to be delivered to BS1, BS2 and BS3 respectively and***
* ***corresponding optimal values of the objective functions z_1, z_2, z_3***

The profit, costs and resources are calculated by /12/, /14/, and /15/.

According to requirements and available data the objective functions are:

$$\max z_1=12x_1+10x_2+11x_3(>,\approx)27000$$
$$\max z_2=9x_1+10x_2+7.5x_3(>,\approx)21400$$
$$\max z_3=8x_1+7x_2+9x_3(>,\approx)18000$$

with tolerance

$$t_1=2100,\ t_2=1700,\ t_3=1400.$$

The weekly capacity of the concrete plant

$$x_1+x_2+x_3(<,\approx)2520, \text{ tolerance } d_1=200.$$

The weekly engagement of 7 transit mixers, according to their working capacities

$$\frac{1}{8.45}x_1+\frac{1}{9.26}x_2+\frac{1}{7.20}x_3\ (\leq,\approx)\ 7x42=294 \text{ h, tolerance } d_2=23 \text{ h}$$

The weekly engagement of 3 concrete pumps

$$\frac{1}{16}x_1+\frac{1}{22}x_2+\frac{1}{26}x_3\ (<,\approx)3x42=126\text{h, tolerance } d_3=10\text{h,}$$

The weekly engagement of 22 workers for interior delivering, placing and consolidating concrete at building site

$$6x_1+7x_2+9x_3(<,\approx)\ 22x42=924 \text{ tolerance } d_4=74.$$

Minimal weekly requests for the concrete:

BS1 $x_1 \geq 588\ m^3$, tolerance $d_5=47m^3$
BS2 $x_2 \geq 756\ m^3$, tolerance $d_6=60\ m^3$
BS3 $x_3 \geq 756\ m^3$, tolerance $d_7=72\ m^3$

The minimal value of the degree of acceptability is $\gamma_1 \geq 0.80$.

These constraints written in full are:

$x_1+x_2+x_3(<,\approx)2520$
$0.118x_1+0.108x_2+0.139x_3(<,\approx)294$
$0.063x_1+0.045x_2+0.038x_3(<,\approx)126$
$0.100x_1+0.117x_2+0.150x_3(<,\approx)924$
$0.033x_1+0.033x_2+0.055x_3(<,\approx)294$
$x_1(>,\approx)588$
$x_2(>,\approx)756$
$x_3(>,\approx)903.$

Using the mentioned computing programme the individual best and worst nonfuzzy solution for constraints (b) and individual objective functions (a) are found. These solutions are

Objective i	x_1 (m^3/week)	x_2 (m^3/week)	x_3 (m^3/week)	z_i^+ (\$)	z_i^+ (\$)
1	734.02	756.00	903.00	26301.29	0
2	588.00	915.95	903.00	21224.00	0
3	734.02	756.00	903.00	19291.00	0

With the obtained values for z_i^+ and z_i^- it is possible to implement the modified Zimmermann's procedure to receive the following results:

- Optimal weekly production for BS1, BS2, and BS3:

  $x_1=635.94\ m^3,\ x_2=863.43\ m^3,\ x_3=903.0m^3$
- Maximal weekly profit $z_1=26199$ \$, coefficient of satisfaction $\alpha_1=0.996$
- Maximal number of points for quality $z_2=21130$, coefficient of satisfaction $\alpha_2=\mathbf{0.996}$
- Maximal number of points for working conditions $z_3=19259$, coefficient of satisfaction $\alpha_3=0.998$
- Coefficient of acceptability of this solution $\Upsilon=0.941$.

For the fuzzy problem the obtained solutions are:

- Optimal weekly production for BS1, BS2, and BS3:

  $x_1=783.50\ m^3,\ x_2=747.11m^3, x_3=892.33\ m^3$
- Maximal weekly profit $z_1=26689$\$, coefficient of satisfaction $\alpha_1=1.015$
- Maximal number of points for quality $z_2=21215$, coefficient of satisfaction $\alpha_2=\mathbf{0.996}$
- Maximal number of points for worker satisfaction $z_3=19529$, coefficient of satisfaction $\alpha_3=1.012$
- Coefficient of acceptability of this solution $\Upsilon=0.852$.

The obtained results point to little difference between fuzzy and nonfuzzy objective functions for the individual best solution. The difference is less that 2%. The coefficients of acceptability of the solutions Υ, indicating the possibility to realize these solutions, are very high. According to this, the decision maker could accept

* the nonfuzzy solution that gives smaller profit with possibility of realization Υ=0,941,
* the fuzzy solution that gives higher profit with possibility of realization Υ=0.852.

The applied computer programme helps the decision maker to vary the values of the coefficient ϒ in the interval [0,1] and to receive the corresponding optimal values of production and profit with corresponding values of possibility.

CONCLUSIONS

The business decision making process in the civil engineering industry can be explained by the fuzzy approach of the multiple objective system technique. The approach described and implemented in this paper is mainly based on Lai and Hwang's cited works. The proposed models with linear objective functions and constraints are based on linear membership functions. The results of the models are obtained by the auxiliary linear programmes. These programmes help the decision maker to take into account the imprecise data such as:

* the expected profit, quality, working conditions, available resources, realized production

to obtain the required optimal solutions with the corresponding coefficients of possibility of their realization.

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