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Edited by Jun Ma, Yilong Yin, Jian Yu, and Shuigeng Zhou

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Editors
Jun Ma
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Preface

Following the success of the 1st International Conference on Fuzzy Systems and Knowledge Discovery (FSKD 2002) in Singapore, FSKD 2005 in Changsha, FSKD 2006 in Xi'an, and FSKD 2007 in Hainan, FSKD 2008 was held jointly with the 4th International Conference on Natural Computation (ICNC 2008) from 18 to 20 October 2008 in Jinan, Shandong, China. FSKD 2008 attracted 1,310 submissions from 38 countries/regions. After rigorous reviews, 631 high-quality papers were included in the FSKD 2008 proceedings, representing an acceptance rate of 48.2%. The joint ICNC-FSKD 2008 received 3,185 submissions, a total of 1,545 papers of which were included in the ICNC-FSKD 2008 proceedings, representing an overall acceptance rate of 48.5%.

Fuzzy systems and knowledge discovery have become not only important parts in the field of Artificial Intelligence but also exciting and emerging interdisciplinary areas in which a wide range of techniques and methods are being studied for dealing with uncertainty and data. The FSKD 2008 featured the most up-to-date research results in fuzzy systems and knowledge discovery as well as promoted cross fertilization over these exciting and yet closely related areas, including computation with words, fuzzy computation, granular computation, data mining, with innovative applications to reliability, finance, commercial, operations research, automata control, and more. In addition to the large number of submitted papers, we were blessed with the presence of several renowned keynote speakers.

On behalf of the Organizing Committee, we thank Shandong University and the International Natural Computation and Knowledge Discovery Association (INCKDA) for sponsorship and logistic support. We also thank the members of the Organizing Committee and the Program Committee for their hard work in the past 18 months. We wish to express our heartfelt appreciation to the keynote speakers, invited session organizers, session chairs, reviewers, and student helpers. Finally, we thank all the authors and participants for their great contributions that made this conference possible and all the hard work worthwhile.

Jun Ma, Yilong Yin, Jian Yu, and **Shuigeng Zhou**
October 2008

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Fuzzy Multi-objective Linear Programming having Probabilistic Constraints: Application in Product-Mix Decision-Making

Ign Suharto[1], Sani Susanto[2], Neneng Tintin Rosmiyanti[3], Arijit Bhattacharya[4]
[1]*Department of Chemical Engineering, Parahyangan Catholic University, Bandung, Indonesia*
[2]*Department of Industrial Engineering, Parahyangan Catholic University, Bandung, Indonesia*
[3]*Department of Mathematics, Padjadjaran University, Jatinangor, Indonesia*
[4]*School of Mechanical & Manufacturing Engineering, Dublin City University, Dublin 9, Ireland*
[1]*suharto@bdg.centrin.net.id,* [2]*sjrh@bdg.centrin.net.id,* [3]*adluthunimut@yahoo.com,* [4]*arijit.bhattacharya@dcu.ie*

Abstract

A fuzzy multi-objective linear programming model having probabilistic constraints is demonstrated in order to make product-mix decision. The proposed model considers fuzziness in presence of multiple objective functions. The most important aspect of the model is that it is able to tackle constraints which are probabilistic in nature. A product-mix problem having real-world data of a food processing industry is illustrated focusing the application of the proposed model.

1. Introduction

This paper concentrates on one of the important aspects of technology management for enterprise producing family of products, i.e., the product-mix problem. The product-mix problem intends to determine the number of each product produced in order to achieve objectives of the enterprise, e.g., maximize profit, minimize wastes, considering limitations of the enterprise e.g., the availability of material, funds, space.

Various forms of Linear Programming (LP) are used [1, 3, 4, 5, 8, 11, 12, 13, 14] for deciding firms' product-mix. However, there are number of flaws with the modelling and application parts of the LP. Among several flaws, certainty of the fulfilment of the whole constraints of the LP model is addressed in this paper. Earlier, two flaws had been addressed [11]: (i) certainty of the parameters of the model [6, 7, 9, 10], and (ii) consideration of multiple objective functions [2]. The synergistic effect of the approach proposed in this paper is able to consider the fuzziness in the decision parameters, in presence of multiple objective functions under the uncertainty of the constraints fulfilment.

2. Definition of the problem

In order to demonstrate the efficacy of the developed LP model having probabilistic constraints we refer to the problem delineated in our previous work [11]. Our previous work [11] deals with a real-world application with fuzzy multiple-objective function. The application was tested with the product-mix problem of *PT Campina Ice Cream Industry*, a market leader in ice cream and frozen food industry located at Surabaya, East Java, Indonesia. Like our previous paper [11], a family comprising three ice cream products – viz., Didi Cup® Chocolate-Vanilla, Bazooka® Chocolate and Homepacks-Chocolate Fudge® – is selected here as a case study.

It is intended to find out the number of products to be manufactured for the ice cream manufacturing company. The Table 1 depicts the objective function as well as the constraints of the product-mix problem indicating the parameters' definitions:

In order to solve the aforesaid problem, the proposed model i.e., fuzzy multi-objective LP having probabilistic constraints [15], comprises of three phases:

(i) Phase I: formulation of the original crisp multi-objective problem, called as problem formulation-1 (PF-1)

(ii) Phase II: development of PF-1 to fuzzy multi-objective problem, called as problem formulation -2 (PF-2)

(iii) Phase III: development of PF-2 to fuzzy multi-objective and probabilistic constraints problem, called as problem formulation -3 (PF-3)

The first two phases (PF-1 & PF-2) have already been described in our previous paper [11]. Readers are referred to paper [11] for further details on the first two phases. Stress is given on the Phase-III in this paper. Thus, the contribution of this paper is mainly directed towards finding the synergistic effects of the fuzzy multi-objective linear programming when probabilistic constraints are considered.

2.1. Problem formulation-1 (PF-1)

There are two objective functions associated with the ice cream manufacturing company (equations 1 & 2):

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Table 1: Ingredients per litre of product

Product	Milk Powder (kgs)	Chocolate Powder (kgs)	Vegetable Oil (kgs)	Profit (Indonesian Rupiah)	Waste (litres)
x_1 = Didi Cup Chocolate-Vanilla	$a_{11}=2$	$a_{21}=2$	$a_{31}=1$	$c_1=5000$	$d_1=4$
x_2 = Bazooka Chocolate	$a_{12}=3$	$a_{22}=3$	$a_{32}=2$	$c_2=6250$	$d_2=2$
x_3 = Homepacks Chocolate Fudge	$a_{13}=6$	$a_{23}=2$	$a_{33}=3$	$c_3=4650$	$d_3=3$
Availability	$b_1=127$	$b_2=52$	$b_3=56$		

$$\max\ z_1=\sum_{j=1}^{3}c_jx_j \quad \dots (1)$$

$$\min\ z_2=\sum_{j=1}^{3}d_jx_j \quad \dots (2)$$

The equation (1) aims at maximizing the total profit, i.e., the sum of all profit gained from the sale of each type of product whereas the equation (2) minimizes the total waste resulted from the production of the three types of product. The constraints of the problem consist of three systems constraints (Equations 3, 4 & 5) and three non-negativity constraints (Equation 6).

$$\sum_{j=1}^{3}a_{1j}x_j\le b_1 \quad \dots (3)$$

$$\sum_{j=1}^{3}a_{2j}x_j\le b_2 \quad \dots (4)$$

$$\sum_{j=1}^{3}a_{3j}x_j\le b_3 \quad \dots (5)$$

$$x_1, x_2, x_3 \ge 0 \quad \dots (6)$$

Constraints, i.e., Equations 3, 4 & 5, depict that the amount of milk powder, chocolate powder, and vegetable oil needed are less than or equal to its availability respectively.

Since there is potential conflict in the fulfilment of the two objectives, tolerances are assumed to resolve the conflict. The tolerances permitted by the ice cream manufacturing company are as follows:

(i) Tolerance 1: at least 75% of the potential maximum profit is targeted to be achieved, and

(ii) Tolerance 2: the total waste is targeted not to exceed 30% of the potential minimum waste.

To include these two tolerances, PF-1 is developed to PF-2. The development of PF-2 is delineated in brief in the next section [11].

2.2. Problem formulation-2 (PF-2)

Let the fuzzified objective functions are z_1' (minimum value) and z_1'' (maximum value) respectively subject to the above-defined constraints. Once the objective function z_1 achieves the value z_1' (or more), or z_1'' (or less), the degree of optimality values achieved by this function are 1 or 0, respectively. When the objective function z_1 achieves any values between z_1'' and z_1', the following fuzzified function determines the degree of satisfaction:

$$\mu_{z_1}(x_1,x_2,x_3)=\begin{cases}0, & \text{if } c_1x_1+c_2x_2+c_3x_3\le z_1''\\ \dfrac{(c_1x_1+c_2x_2+c_3x_3)-z_1''}{z_1''-z_1'}, & \text{if } z_1''\le c_1x_1+c_2x_2+c_3x_3\le z_1'\\ 1 & \text{if } c_1x_1+c_2x_2+c_3x_3\ge z_1'\end{cases} \quad \dots (7)$$

The following function is defined for objective function z_2 in the same fashion to that of Equation (7) subject to the above defined constraints:

$$\mu_{z_2}(x_1,x_2,x_3)=\begin{cases}0, & \text{if } d_1x_1+d_2x_2+d_3x_3\ge z_2''\\ \dfrac{z_2''-(d_1x_1+d_2x_2+d_3x_3)}{z_2''-z_2'}, & \text{if } z_2'\le d_1x_1+d_2x_2+d_3x_3\le z_2''\\ 1 & \text{if } d_1x_1+d_2x_2+d_3x_3\le z_2'\end{cases} \quad \dots (8)$$

Once the Equations (7) & (8) are framed, the PF-1 is transformed into a multi-objective problem maximizing the degree of satisfaction of the decision-maker by quantifying the objective functions z_1 and z_2, as follows:

$$\text{Maximize } \mu_{z_1}(x_1,x_2,x_3) \quad \dots (9)$$

$$\text{Maximize } \mu_{z_2}(x_1,x_2,x_3) \quad \dots (10)$$

subject to the constraints (3)–(6).

This multi-objective optimization problem is then modified to a single objective optimization problem by applying the maxi-min criterion:

$$\max\ \alpha \quad \dots (11)$$

subject to the constraints (3)–(6), and the additional constraints (12) to (16):

$$\mu_{z_1}(x_1,x_2,x_3)\ge\alpha \text{ or } \frac{(c_1x_1+c_2x_2+c_3x_3)-z_1''}{z_1''-z_1'}\ge\alpha \quad \dots (12)$$

$$\mu_{z_2}(x_1,x_2,x_3)\ge\alpha \text{ or } \frac{z_2''-(d_1x_1+d_2x_2+d_3x_3)}{z_2''-z_2'}\ge\alpha \quad \dots (13)$$

$$c_1x_1 + c_2x_2 + c_3x_3 \ge (0.75).(z_1') \text{ (Tolerance 1)} \quad \dots (14)$$

$$d_1x_1 + d_2x_2 + d_3x_3 \le (0.30).(z_2'') \text{ (Tolerance 2)} \quad \dots (15)$$

$$0\le\alpha\le1 \quad \dots (16)$$

In reality, some of the parameters defined in the nomenclature section of Section 2.1 are probabilistic in nature. In order to accommodate probabilistic constraints, PF-2 is developed further into PF-3. In the following illustration the constraints (3)-(5) are hypothetically treated as probabilistic nature.

2.3. Problem formulation-3 (PF-3)

Let the following uncertainty is allowed in the constraints of equations (3)-(5):

$$P\left(\sum_{j=1}^{n} a_{ij}x_j \le b_i\right) \ge (1-\alpha_i) \quad \ldots (17)$$

where α_i represents the probability for the non-fulfillment of constraint i, where i = 1, 2, 3.

The following assumptions are made in order to accommodate uncertainty in the constraints:

(i) a_{ij} are normally distributed random variables, that is $a_{ij} \approx N(\mu_{ij}, \sigma_{ij}^2)$, and

(ii) b_i are normally distributed random variables, that is $b_i \approx N(\mu_i, \sigma_i^2)$, where i, j = 1,2,3.

Let us define $$\tilde{g}_i = \sum_{j=1}^{3} \tilde{a}_{ij}x_j - \tilde{b}_i \quad \ldots (18)$$

$\tilde{g}_i$ is normally distributed with:

$$\mu_{\tilde{g}_i} = E[\tilde{g}_i] = \sum_{j=1}^{3} E[\tilde{a}_{ij}]\, x_j - E[\tilde{b}_i] \quad \ldots (19)$$

and $$\sigma_{\tilde{g}_i}^2 = \mathbf{x}^T D_i \mathbf{x} \quad \ldots (20)$$

where, $$\mathbf{x} = (x_1 \quad x_2 \quad x_3 \quad 1)^T \quad \ldots (21)$$

and D_i, the covariance matrix,

$$= \begin{bmatrix} \sigma_{a_{i1}}^2 & \mathrm{cov}(\tilde{a}_{i1},\tilde{a}_{i2}) & \mathrm{cov}[\tilde{a}_{i1},\tilde{a}_{i3}] & \mathrm{cov}[\tilde{a}_{i1},\tilde{b}_i] \\ \mathrm{cov}[\tilde{a}_{i2},\tilde{a}_{i1}] & \sigma_{a_{i2}}^2 & \mathrm{cov}[\tilde{a}_{i2},\tilde{a}_{i3}] & \mathrm{cov}[\tilde{a}_{i2},\tilde{b}_i] \\ \mathrm{cov}[\tilde{a}_{i3},\tilde{a}_{i1}] & \mathrm{cov}[\tilde{a}_{i3},\tilde{a}_{i2}] & \sigma_{a_{i3}}^2 & \mathrm{cov}[\tilde{a}_{i3},\tilde{b}_i] \\ \mathrm{cov}[\tilde{b}_i,\tilde{a}_{i1}] & \mathrm{cov}[\tilde{b}_i,\tilde{a}_{i2}] & \mathrm{cov}[\tilde{b}_i,\tilde{a}_{i3}] & \sigma_{b_i}^2 \end{bmatrix} \quad \ldots (22)$$

A quantity, S_{α_i}, is defined as follows:

$$\Phi(S_{\alpha_i}) = 1 - \alpha_i \quad \ldots (23)$$

where Φ is the cumulative distribution function of a normal standard random variable.

Mathematically the following relation is established:

$$P\left(\sum_{j=1}^{n} a_{ij}x_j \le b_i\right) = P\left(\frac{\tilde{g}_i - \mu_{\tilde{g}_i}}{\sigma_{\tilde{g}_i}} \le -\frac{\mu_{\tilde{g}_i}}{\sigma_{\tilde{g}_i}}\right) = \Phi\left(-\frac{\mu_{\tilde{g}_i}}{\sigma_{\tilde{g}_i}}\right) \ge 1-\alpha_i \quad \ldots (24)$$

From eqns. (23) & (24) one gets: $$-\frac{\mu_{\tilde{g}_i}}{\sigma_{\tilde{g}_i}} \ge S_{\alpha_i} \quad \ldots (25)$$

and from equations (19), (20) and (25) the following relation is established for i= 1, 2, 3:

$$\sum_{j=1}^{3} E[\tilde{a}_{ij}]x_j - E[\tilde{b}_i] + S_{\alpha_i}\sqrt{x^T D_i x} \le 0 \quad \ldots (26)$$

The complete PF-3 model is summarised below:

max α

subject to: $\sum_{j=1}^{3} E[\tilde{a}_{ij}]x_j - E[\tilde{b}_i] + S_{\alpha_i}\sqrt{x^T D_i x} \le 0$,

$\mu_{z_1}(x_1,x_2,x_3) \ge \alpha$ or, $\frac{(c_1x_1 + c_2x_2 + c_3x_3) - z_1''}{z_1'' - z_1'} \ge \alpha$,

$\mu_{z_2}(x_1,x_2,x_3) \ge \alpha$ or, $\frac{z_2'' - (d_1x_1 + d_2x_2 + d_3x_3)}{z_2'' - z_2'} \ge \alpha$,

$c_1x_1 + c_2x_2 + c_3x_3 \ge (0.75)(z_1')$ (Tolerance 1),

$d_1x_1 + d_2x_2 + d_3x_3 \le (0.30)(z_2'')$ (Tolerance 2),

$x_1, x_2, x_3 \ge 0, 0 \le \alpha \le 1$,

wherein: the constraints of equations (12)-(15) deal with the fuzzy multi-objective property, and constraint of equation (26) deals with the probabilistic aspect of the fulfillment of constraints (3)-(5).

3. Numerical Illustration

In this section efficacy of the models PF-1, PF-2 and PF-3, as well as the synergistic effect of the whole model, are presented illustrating the numerical example of the ice cream manufacturing company. Each presentation consists of two parts, i.e., the numerical model and its solution. In the sub-sections below equations are numbered with single and double apostrophes. This has been done in order to have resemblance with the original equations.

3.1. Solution with PF-1 model

The following equations are obtained using the data of Table 1 in PF-1 model:

Maximize $z_1 = 5000x_1 + 6250x_2 + 4650x_3$ ... (1')

Minimize $z_2 = 4x_1 + 2x_2 + 3x_3$ ... (2')

subject to $2x_1 + 3x_2 + 6x_3 \le 127$ ... (3')

$2x_1 + 3x_2 + 2x_3 \le 52$ ... (4')

$1x_1 + 2x_2 + 3x_3 \le 56$ ... (5')

$x_1, x_2, x_3 \ge 0$ ... (6')

The values of z_1' and z_1'' are 130 000 and 0 respectively. Similarly, the values of z_2' and z_2'' are z_2'= 0 and z_2''= 104

3.2. Solution with PF-2 model

Using the data of Table 1 the following optimal solution is obtained:

Table 2: Ingredients per litre of product (hypothetical)					
Product	Milk Powder (kgs)	Chocolate Powder (kgs)	Vegetable Oil (kgs)	Profit (Indonesian Rupiah)	Waste (litres)
Didi Cup Chocolate-Vanilla	$a_{11} \approx$ N(2;0.005)	$a_{21} \approx$ N(2;0.003)	$a_{31} \approx$ N(1;,0.001)	$c_1 = 5000$	$b_1 = 4$
Bazooka Chocolate	$a_{12} \approx$ N(3;0.001)	$a_{22} \approx$ N(3;0.004)	$a_{32} \approx$ N(2;0.002)	$c_2 = 6250$	$b_2 = 2$
Homepacks Chocolate Fudge	$a_{13} \approx$ N(6;0.002)	$a_{23} \approx$ N(2;0.005)	$a_{33} \approx$ N(3;0.005)	$c_3 = 4650$	$b_3 = 3$
Availability	$b_1 \approx$ N(127;3)	$b_2 \approx$ N(52;2)	$b_3 \approx$ N(56;0.5)		
α_i = the probability for the non-fulfillment of constraint *i*	$\alpha_1 = 0.05$	$\alpha_2 = 0.10$	$\alpha_3 = 0.01$		

x_1 = 0, the ice cream manufacturing company does not produce any 1 litre package of Didi Cup® Chocolate-Vanilla;
x_2 = 15.6, the ice cream manufacturing company produces 15.6 units of 1 litre package of Didi Cup Bazooka® Chocolate;
x_3 = 0, the ice cream manufacturing firm does not produce any 1 litre package of Homepacks Chocolate Fudge®, and
α = 0.70.

The above solution was illustrated in details in our previous paper [11].

3.3. Solution with PF-3 model

Solution with this model is based on the data presented in the Table-2. All probabilistic variables are having hypothetical distributions and variances, but with actual means.

The constraint corresponds to constraints (3) and (3') is: $P(2x_1 + 3x_2 + 6x_3 \le 127) \ge (1-\alpha_1)$=0.95 ... (3")

From equation (23) one gets $\Phi(S_{\alpha_1}) = 1-\alpha_1$=0.95.

Using standard normal distribution table: S_{α_1}=1.645 ... (27)

Similarly, the constraint corresponds to constraints (4) and (4') is:

$P(2x_1 + 3x_2 + 2x_3 \le 52) \ge (1-\alpha_2)$=0.90 ... (4")

From equation (23) and standard normal distribution table

S_{α_2}=1.281 ... (28)

The constraint corresponds to constraints (5) and (5') is: $P(1x_1 + 2x_2 + 3x_3 \le 56) \ge (1-\alpha_3)$=0.99 ... (5")

From equation (23) and standard normal distribution table

S_{α_3} = 2.326 ... (29)

In order to calculate the covariance matrices D_1, D_2 and D_3, the following quantities are calculated:

$\text{cov}(x_1,x_2), \text{cov}(x_2,x_1), \text{cov}(x_1,x_3), \text{cov}(x_2,x_3)$ and $\text{cov}(x_3,x_2)$. The calculation is restricted to the above-mentioned quantities as

$$\text{cov}(\tilde{a}_{11},\tilde{a}_{13}) = \text{cov}(\tilde{a}_{13},\tilde{a}_{11}) = 0,$$
$$\text{cov}(\tilde{a}_{12},\tilde{a}_{13}) = \text{cov}(\tilde{a}_{13},\tilde{a}_{12}) = 0,$$
$$\text{cov}(\tilde{a}_{21},\tilde{a}_{22}) = \text{cov}(\tilde{a}_{22},\tilde{a}_{21}) = 0,$$
$$\text{cov}(\tilde{a}_{21},\tilde{a}_{23}) = \text{cov}(\tilde{a}_{23},\tilde{a}_{21}) = 0,$$
$$\text{cov}(\tilde{a}_{22},\tilde{a}_{23}) = \text{cov}(\tilde{a}_{23},\tilde{a}_{22}) = 0,$$
$$\text{cov}(\tilde{a}_{31},\tilde{a}_{32}) = \text{cov}(\tilde{a}_{32},\tilde{a}_{31}) = 0,$$
$$\text{cov}(\tilde{a}_{31},\tilde{a}_{33}) = \text{cov}(\tilde{a}_{33},\tilde{a}_{31}) = 0,$$
$$\text{cov}(\tilde{a}_{32},\tilde{a}_{33}) = \text{cov}(\tilde{a}_{33},\tilde{a}_{32}) = 0$$

Therefore, matrices formed are:

$$D_1 = \begin{bmatrix} 0.05 & 0 & 0 & 0 \\ 0 & 0.01 & 0 & 0 \\ 0 & 0 & 0.02 & 0 \\ 0 & 0 & 0 & 5 \end{bmatrix} \quad \text{... (30)}$$

$$D_2 = \begin{bmatrix} 0.03 & 0 & 0 & 0 \\ 0 & 0.04 & 0 & 0 \\ 0 & 0 & 0.05 & 0 \\ 0 & 0 & 0 & 2 \end{bmatrix} \quad \text{... (31)}$$

$$D_3 = \begin{bmatrix} 0.001 & 0 & 0 & 0 \\ 0 & 0.002 & 0 & 0 \\ 0 & 0 & 0.005 & 0 \\ 0 & 0 & 0 & 0.5 \end{bmatrix} \quad \text{... (32)}$$

The solution to PF-3 is obtained using LINGO® 8.0 software. The solution obtained is: x_1 = 0, x_2 = 15.6, x_3 = 0 and α = 0.70, which is exactly the same as that of the solution to PF-2.

4. Discussion and conclusion

In reality constraints are multiple, probabilistic in nature. The PF-3 model as well as the entire fuzzy multi-objective probabilistic model is helpful under such real-world scenario. It is noticed that the solution of the PF-3 is identical to that of the solution of PF-2. In fact, due to the additional constraint (26), the solution of the PF-3 is at most as good as the solution to PF-2. Introduction of such probabilistic feature in constraint makes the whole model uncertain and there is every probability to get some kind of worse solution than that of PF-2. Thus, phase-wise, i.e., PF-1, PF-2 & PF-3, solution of the whole model is presented in this paper in order to have a comparative study of these solutions. It is noticed from those solutions that introduction of such probabilistic constraints, which is the real-world situation, in the model doesn't influence the solution of the ice cream manufacturing company if the whole model presented above is considered. In future work one may study the stability of such model while dealing with large scale optimization.

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