A new approach on planning and decision making in engineering and construction industry

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Abstract-In recent years engineering and construction industry faces formidable challenges in control project and optimization of management decision making. The requirements and challenges of today's world have made managers to explore new methods in dealing with solving management problems, methods with high flexibility, which can adopt plans to real conditions can help one to make a decision at right time.

This paper proposes a new method to obtain the optimal solution in construction environment with uncertainty and dynamic. Since linear programming is the most natural mechanism for formulating a vast array of problems with the modest effort, we use fuzzy linear programming and Matlab computation to solve this problem. In this research, we are modeling uncertainty and dynamic of engineering and construction industry with fuzzy theory. The considerable ratio of data about uncertainties is linguistic data and cannot be formulated with classical mathematics, so we use fuzzy theory for the computational model of the linguistic term of expert.

After preparation of the dynamic fuzzy linear programming model (DFLP) we solve the optimization problem. Dynamics of the DFLP model able the system to provide decision making in environmental changes.

Keywords-fuzzy modeling; fuzzy decision making; planning; dynamic; linguistic data; uncertainty handling .

1. Introduction

The engineering and constructions industry faces formidable challenges, as a whole, the industry worldwide continues to perform unsatisfactorily. It suffers from low profit and persistent project overruns in schedule and budget. [1]

In this paper, a methodology for fuzzy linear programming is discussed for modeling uncertain and dynamic environment of engineering and construction industry.

Many authors have used fuzzy-linear programming in planning decision making problems [2, 8, 9, 10]. There are various types of membership function which express uncertainty of fuzzy systems, such as linear membership function [13,15] (Trapezoidal and triangular), a tangent type of a membership function [12], an exponential membership function [3], an interval linear membership function and hyperbolic membership function.

Fuzzy linear programming models are robust and can be used in different problems. In these models decision maker could easily considers the existing alternative under given constrains, and also develops new alternatives by considering all possible situations. [17]

A fuzzy mathematical programming problem defined with a non- linear membership function (MF) results in non-linear programming. Usually a linear MF is employed in order to avoid non-linearity. Nevertheless, there are some difficulties such as non-flexibility in using linear MF. What is the benefit of flexibility? Flexibility provide decision maker to adopt a problem to real condition and help one to apply his strategy in decision making at any time [12]. So non-flexibility make some difficulties to consider dynamic situations in decision making.

In order to solve this issue Carlson and Korhomen [1986] used exponential for MFs, which is not as restrictive as the linear form, but it is not flexible enough to describe the vagueness hidden in the parameters [4]. Vasant [2003] employed a non-linear logistic function and proposed s-curve MF which is more flexible and convenient.

So in this paper we use s-carve MFs and propose a new method for preventing non-linear problem solving, which is a combination of the proposed model of Abraham and Lozarevic [2003] and Barsoum and Vasant [2007].

1.1 S-curve Membership function

The modified s-curve MF (Bhattacharya and Vasant 2003) is defined as:

$$\mu(x)=\begin{cases}1 & x<x^{a}\\ 0.999 & x=x^{a}\\ \dfrac{B}{1+Ce^{\alpha x}} & x^{a}<x<x^{b}\\ 0.001 & x=x^{b}\\ 0 & x>x^{b}\end{cases} \qquad (1)$$

Where B and C are scalar constants and α, $0<\alpha<\infty$ is a fuzzy parameter which measures the degree of vagueness. Where α=0 correspond to crisp situation and μ(x), $0<\mu(x)<1$ is the degree of satisfaction.

Figure (1) shows the change in shape of S-curve MF according to different value of α.

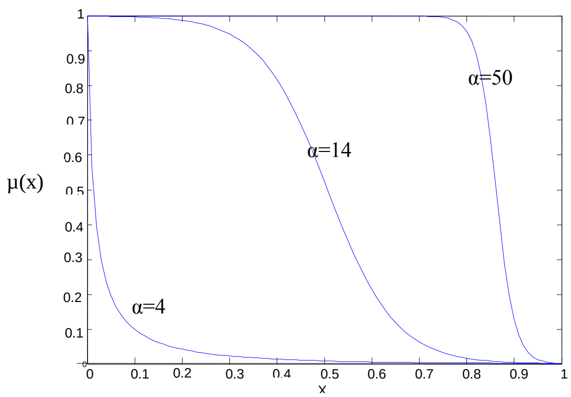

Figure (1) : Variation of μ(x) with respect to α

As mentioned, non-linear MFs bring non-linear programming , Vasant proposed the following method to prevent non-linearity, for problem with fuzzy resources:

$$Max \quad \sum_{j=1}^{n} c_j x_j$$
$$subject\ \ to:\sum_{i=1}^{m}\sum_{j=1}^{n} a_{ij}x_j \le \hat{b}_i \qquad (2)$$

Where $\hat{b}_i$ is uncertain and can be represented by S-curve MF.

$$\hat{b}_i\Big|_{\mu b_i} = b_i^{a} + \left(\frac{b_i^{b}-b_i^{a}}{\alpha}\right) Ln\frac{1}{c}\left(\frac{B}{\mu_{bi}}-1\right) \qquad (3)$$

In equation (3), the best value for the objective function, is reached at the fixed value of μ_b. (Calsson and Korhanen [1986]) when:

$$\mu_b=\mu_{bi} \quad \text{i=1,2,…} \qquad (4)$$

By using equation (2) with values of α, B, C (readers are encouraged to refer to Vasant el at. [2007]) the fuzzy linear programming (FLP) problem has been formulated, and all the coefficients are parameterized. However, it will not be possible to use the linear parametric formulation to solve the FLP problem since the membership functions are non-linear. It is needed to carry out a series of experiments for different values degree of satisfaction. The interval between two adjacent μ_{bi} values can be arbitrary but has to be as small as possible to reach a level of precision in the optimal solution[4].

The final answer of an example that has been solved by Vasant method presented in figure (2). (The example will be explained perfectly in section 4)

In figure (2) μ is represents the degree of satisfaction and z_1 is the profit function, and α vagueness parameter. The decision maker has to be satisfied with the profit obtained through the FLP process with respect to degree of satisfaction and disparate value of α.

It is found that the s-curve membership function with varies values of α offer an acceptable solution with certain degree of satisfaction in fuzzy environment. The relationship between z, μ, and α is given in figure (2), this figure is very useful for decision maker to find the profit at any given value of α with degree of satisfaction μ. This means one should satisfy with a degree of satisfaction when come to making decisions in fuzzy environment [12].

So there must be an interaction between the analyst and the decision maker to continue this process until the decision maker is satisfied with the referenced solution.

Thus further researches will be conducted on flexible computation techniques using the modified s-curve MF and dynamic MF to make more precision results [12].

Vasant proposes possibilistic linear programming (PLP) for analyzing the outcomes in figure (2).

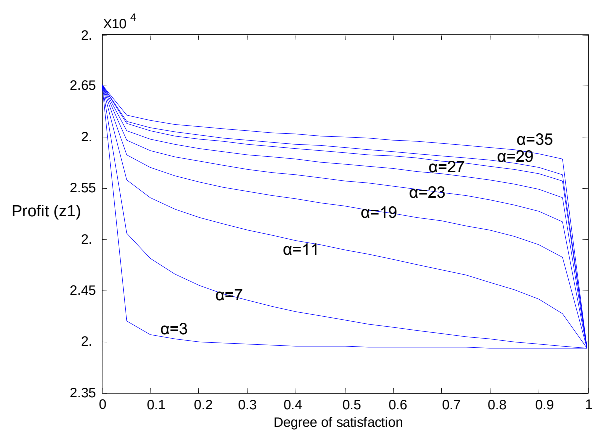

Figure (2): Optimal z_1 values vs. degree of satisfaction for disparate fuzziness α (3, 7, 11, 19, 23, 27, 29, 35)

1.2 Trapezoidal Membership function

Abraham and Lazarvic [2003] proposed a method for solving Hybrid fuzzy linear programming by using linear MF, that is similar to the method proposed by Werner [1987] on solving fuzzy linear programming with fuzzy resources.
In this method there are two type of MF, a set of MFs for degree of satisfaction of constrains (μ_i) and one MF for degree of satisfaction of objective function (μ_0) :

$$\begin{aligned} &\quad\quad cx \\ Max &\quad Ax < \hat{b}_i \\ &\quad x \ge o \end{aligned} \tag{5}$$

$$\mu_i(x) = \begin{cases} 1 & if \quad (Ax)_i < b_i \\ 1-[(Ax)_i - b_i]/t_i & if \quad b_i \le (Ax)_i \le b_i + t_i \\ o & if \quad (Ax)_i > b_i + t_i \end{cases} \tag{6}$$

$$\mu_o(x) = \begin{cases} 1 & if \quad cx > z^1 \\ 1-\dfrac{z^1 - cx}{z^1 - z^o} & if \quad z^o \le cx \le z^1 \\ o & if \quad cx < z^o \end{cases} \tag{7}$$

Where t_i (> 0) be the tolerance of i'th resource b_i, and z^0, z^1 are the answers of following LP:

$$\begin{aligned} &\text{Maximize } z^o = cx \\ &Subject\ to: (Ax)_i \le b_i \quad i = 1,2,\dots,m \\ &x \ge 0 \end{aligned} \tag{8}$$

$$\begin{aligned} &\text{Maximize : } z^1 = cx \\ &Subject\ to: (Ax)_i \le b_i + t_i \quad i = 1,2,\dots,m \\ &x \ge 0 \end{aligned} \tag{9}$$

Since the constraints and objective functions are represented by the membership function respectively Werner [1987] used the max-min method to solve the multiple objective optimization problem, specifically, the problem becomes:

$$\begin{aligned} &\max\ \min\left[\mu_o(x), \mu_1(x), \dots, \mu_m(x)\right] \\ &x \ge 0 \end{aligned} \tag{10}$$

or equivalently :

$$\begin{aligned} &\text{maximize} \quad \theta \\ &\text{subject to : } \mu_o(x) \ge \theta \\ &\qquad\qquad \mu_i(x) \ge \theta \qquad i = 1,2,3,\dots,m \\ &\qquad\qquad \theta \in [0,1]\ ,\ x \ge 0 \end{aligned} \tag{11}$$

This method assigns optimal decision variables precisely but it is not flexible and dynamic.
Abraham [2003] to consider multi criteria decision making problems proposed the below objective function:

$$\max\ \theta + \delta \sum_{i=0}^{n} w_i \mu_i \tag{12}$$

Where θ is the minimum value of μ_i and μ_0 (equation 11), δ is a sufficiently small positive number and ω_i is the weights between objective and constrains.
ω_i would appointed proportionate to μ_i consider to experience of expert.
In this optimization problem, success directly depends on modeling the objective functions of the problem concerned and the modeling of the variables. So more research is needed in order to find out whether such models could support decision making processes in any industry and construction activities [7]. Flexibility is another issue to consider.

2. Proposed model

The dynamic fuzzy linear programming (DFLP) can be formulated as :

$$\sum_{j=1}^{n} c_j x_j \tag{13}$$

$$\text{Subject to : } \sum_{i=1}^{m}\sum_{j=1}^{n} a_{ij} x_j \le \hat{b}_i$$

$$\hat{b}_i\Big|_{\mu_{bi},\alpha_i} = b_i^a + \left(\frac{b_i^b - b_i^a}{\alpha_i}\right) Ln\frac{1}{c}\left(\frac{B}{\mu_{bi}} - 1\right)$$

In this model $\hat{b}_i$ is function of α_i and μ_{bi} where $\hat{b}_i$ has uncertain and dynamic nature. Uncertainty of $\hat{b}_i$ is because of imprecise basic information and dynamic nature of $\hat{b}_i$ is because of environmental conditions and organization facilities are in continues process of change.
We use α_i as parameter to consider heuristic and momental information of experts and environmental condition that can effect on decision making and final strategy of the decision maker. The parameter α_i is a positive real number where determined by decision maker through heuristical and experiential, this parameter make the decision making more flexible and dynamic.
As referred Abraham and Werner used max-min method for finding the results, in max-min method increasing of μ_i (degree of satisfaction of constrains) will decreasing μ_0 (degree of satisfaction of objective function) and vice versa, in fact the final optimum results will be created by trade off between μ_0, μ_i and lead to suitable μ.

We employ this idea by using s-curve MF. On the base of variety of μ_b between [0,1] , in specific interval, the objective function z will be drown on μ_b, for each μ_b we calculate inconsistent μ_0 and will be drown the objective function z on μ_o . As we need to make trade off between μ_{bi}, μ_0 and in another words we want to maximize the minimum value of μ_{bi} and μ_0, the conjunction point of these two curves will be determined the best solution. So in DFLP model the precise solutions will be approach and there is no need to analyze the output results.

2.1 Algorithm for the proposed model

The procedure for obtaining the optimal solution for dynamic fuzzy linear programming is described as follows:

Step 1: Formulating the optimization problem in the form of linear or multi-objective programming problem.

Step 2: Set the s-curve MF for uncertain resource parameter for the preference values and tolerances.

Step 3: Select the fuzzy parameter α_i for each fuzzy parameter according to expert experience.

Step 4: Generate the fuzzy parameter $\hat{b}_i$ by using μ_{bi} and α_i.

Step 5:Computing the optimization problem (Eq.13) by using Matlab fuzzy tool box and select the suitable μ by determining the conjunction point of μ_0 and μ_b.

Step 6: Determining the decision variable precisely according to what found in step 5.

Step 7: Change the values of α_i consider to which interviews with expert and obtain the optimal solution at any situation.

3. Case study and numerical results

The construction industry's problem, as stated by Lazarvic and Abraham (2003) and Vasant (2007) is delineated as follows:

The operations of a concrete manufacturing plant, which produces and transport concrete to the building site, have been analyzed here. Fresh concrete is produced at a central concrete plant and transported by seven transit mixers over the distance ranging 1500-3000 m to the three construction sites. Three concrete pumps and 11 interior vibrators are used for delivering placing, and consolidating the concrete at each construction site.

The decision maker task is to maximize the profit, the index of work quality and worker satisfaction by utilizing the optimize plant capacity while meeting the three construction site's concrete and other resource require through a flexible schedule.

3.1 Modeling and formulations

The main purpose of this paper is to find out the optimal value of the objective functions under uncertain and dynamic environment. Another purpose is to obtain the actual quantities of concrete, which have to be delivered to the sites A, B and C, respectively yet another objective is to utilize the idle resource variable in the labor -hour of manpower of the concrete plant.

Table 1 illustrates the manufacturing capacities of the plant, operational capacity of the concrete mixer, interior vibrator, pumps and manpower requirement at the three construction sites.

3.2 Objective functions

Success of any decision model will directly depend on the formulation of the objective function taking into account all the influential factors. We modeled the final objective function taking into account three independent factors: (1) profit expressed as $/m^3 (2) index of work quality (performance) and (3) worker satisfaction.

Profit: The expected profit as related to the volume of concrete to be manufactured is modeled as the first objective and is shown in Table 2. The minimal expected weekly profit as a fuzzy value is z_1=27000$ per week with tolerance p_1=2100.

Table 2: Modeling profit as an objective

Site	**A**	**B**	**C**
Expected profit (AU$/m^3)	12	10	11

Index of quality: equally or sometimes more important than the profit, quality plays an important role in every industry. We modeled the index of quality at construction

Table 1: Concrete plant capacity and construction site's resource demands

	Concrete plant	Site A	Site B	Site C	Remarks
Plant capacity (m^3/week)	2520				
Transit mixer (m^3/h) (total=7)		8.45	9.26	7.26	Operated by 7 workers
Concrete pumps (m^3/h) (total=3)		16	22	26	Operated by 6 workers
Interior vibrators (m^3/h) (total=11)		4	4	4	
Worker requirement	5	6	7	9	
Minimal concrete requirement (m^3/week)		588	756	903	
Tolerance (m^3)		47	60	72	

sites, as the second objective. The index is ranged from 5 points/m^3 (bad) quality to 10 points/m^3 (excellent) quality and the assigned values are shown in Table 3, The minimal expected total weekly number of points for quality, as fuzzy value, is z_2=21400 with tolerance p_2=1700 points.

Table 3: Modeling index of quality as an objective

Site	A	B	C
Index of quality	9	10	7.5

Worker satisfaction index: we modeled the index of worker satisfaction as the third objective and is ranged from 5 to 10 points per m^3 of produced, transported and placed concrete. The assigned values are depicted in Table 4. The minimal expected total weekly number of points as a fuzzy value is z_3=18000 with tolerance p_3=1400.

Table 4: Modeling worker satisfaction index as an objective

Site	A	B	C
Worker satisfaction index	8	7	9

According to problem requirements and available data (Lazarvic and Abraham) the objective functions can be modeled as follows: (Zimmerman 1987).

Max $z_1 = 12\,x_1 + 10\,x_2 + 11\,x_3$ with tolerance $p_1 = 2100$ (profit)

Max $z_2 = 9\,x_1 + 10\,x_2 + 7.5\,x_3$ with tolerance $p_2 = 1700$ (index of quality)

Max $z_3 = 8x_1 + 7x_2 + 9x_3$ with tolerance $p_3 = 1400$ (worker satisfaction index)

$x_1 + x_2 + x_3\,(\leq,\ \hat{}\ )\ 2520$ with tolerance d_1=200 (weekly capacity of the concrete plant)

$0.12\,x_1 + 0.11\,x_2 + 0.14\,x_3\,(\leq,\ \hat{}\ )\ 294$ h with tolerance d_2 = 23 h (weekly engagement of seven transit mixers)

$0.06\,x_1 + 0.05\,x_2 + 0.04\,x_3\,(\leq,\ \hat{}\ )\ 126$ h

With tolerance d_3=10h (weekly engagement of three concrete pumps)

$0.16\,x_1 + 0.14\,x_2 + 0.11\,x_3\,(\leq,\ \hat{}\ )\ 924$ with tolerance d_4=74 (weekly engagement of 22 workers for interior delivering , placing and consolidating concrete at sites A, B and C)

Minimal weekly requests for concrete from three construction sites are as follows:

Site A: $x_1 \geq 588\ m^3$, tolerance $d_5 = 47m^3$

Site B: $x_2 \geq 756\ m^3$, tolerance $d_6 = 60\ m^3$

Site C: $x_3 \geq 903\ m^3$, tolerance $d_7 = 72\ m^3$

By using parametric linear programming techniques and Matlab Lp Tool Box the above equation are solved by written Matlab M-file on base of the proposed algorithm, the obtained results are summarized in the next section.

3.3 Computational results

In this section, we will compute the solution using the proposed DFLP and the result is compared with those of Abraham (2003) and Vasant (2007).

In Table 5, 6, 7, 8 the fuzzy parameters that used in the construction problem are categorized, b_i for i=1,…,4, BL_j for j=1, 2, 3, p_k for k=1, 2, 3 could be formulate as constrains in fuzzy linear programming. For each of the constrains s-curve MF with α_i and μ_{bi} would be set. μ_{bi} has values between [0 1] with an interval of 0.0499 and α_i which obtain by decision maker through heuristically and experientially.

Table 5: Resource parameter

bi	
b_1	Weekly capacity of concrete plant
b_2	Weekly engagement of seven transit
b_3	Weekly engagement of three concrete pumps
b_4	Weekly engagement of 22 workers for in interior delivering , placing and consolidating concrete at site A, B , and C)

Table 6: Minimal Weekly request for concrete

BLj	
BL_1	Minimal expected value for concrete in site A
BL_2	Minimal expected value for concrete in site B
BL_3	Minimal expected value for concrete in site C

Table 7: Minimal expected value for objective functions

p_k	
p_1	Minimal expected value for profit
p_2	Minimal expected value for index of quality
p_3	Minimal expected value for worker satisfaction

Table 8: Dynamic fuzzy parameter

α_i	
α_1	Dynamic fuzzy parameter of b_1
α_2	Dynamic fuzzy parameter of b_2
α_3	Dynamic fuzzy parameter of b_3
α_4	Dynamic fuzzy parameter of b_4
α_5	Dynamic fuzzy parameter of BL_1
α_6	Dynamic fuzzy parameter of BL_2
α_7	Dynamic fuzzy parameter of BL_3
α_8	Dynamic fuzzy parameter of p_1
α_9	Dynamic fuzzy parameter of p_2
α_{10}	Dynamic fuzzy parameter of p_3

To formulate linguistic terms of fuzzy variable α_i, interviews with experts could be utilized. Very low, low, medium, high, very high are examples suggested for

Table 9: Comparative analysis

	Solution found from DFLP model					Fuzzy solution of Lazarevic and Abraham				Solution found from PLP model			
	z	x_1	x_2	x_3	μ	z	x_1	x_2	x_3	z	x_1	x_2	x_3
z_1	26826	566	1047	869	0.6017	26301.29	734.02	756.00	903.00	25488.71	635	816	975
z_2	22086	566	1047	869		21224.00	588.00	915.95	903.00	20435.70	786	786	939
z_3	19682	566	1047	869		19291.00	734.02	756.00	903.00	18949.72	756	786	903

linguistic interviews. The results in Table 9 are obtained from DFLP model when α_i=13.81 for i=1, 2,…,10 (medium level consider to suggested examples) and compared with results from PLP model of Vasant [2007] with value of vagueness α=13.81 (PLP model is a solution for analyze the outcome results in Vasant method) and the results of Abraham and Lazarevic (2003) model. It is noticed in Table 9 that the DFLP model presented in this paper results in better solution to those of the solutions reported by Lazarevic [2003] and Vasant [2007].

In order to handling multi-objective fuzzy linear programming that stated in this construction problem, we set the objective function as below:

Maximize $z = z_1 + z_2 + z_3$

Subject to:

$$z_1(\geq,\wedge)27000 \quad tolerance\ p_1 = 2100$$

$$z_2(\geq,\wedge)21400 \quad tolerance\ p_2 = 1700$$

$$z_3(\geq,\wedge)18000 \quad tolerance\ p_3 = 1400$$

Where z_1, z_2, z_3 are objective functions and $(\geq,\wedge)$ is soft or fuzzy inequality with known tolerance of fuzzy objective constrains and s-curve membership functions as other constrains.

Figure (3) shows the objective function curve upon μ_b (decreasing) and μ_0 (increasing), the conjunction point of these two curves is the optimal μ (degree of satisfaction) for α_i =13.81 i=1, 2, …., 10.

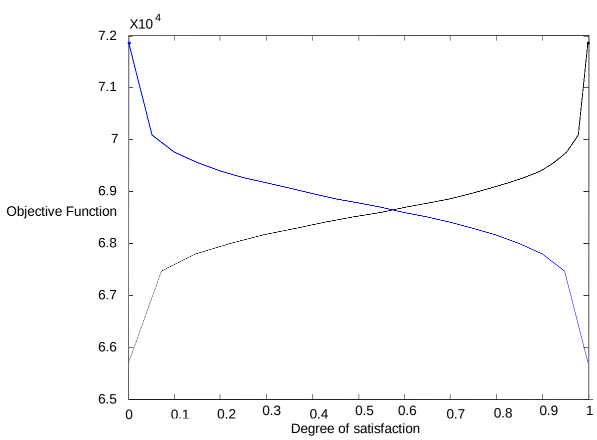

Figure (3): objective function in terms of μ_0 (--), μ_b (-) for α_i=13.81

In a dynamic environment the availability of a fuzzy resource might be changed. For example, if the availability of a weekly engagement seven transit mixer because of good weather or bad weather be high or low the decision maker would increase or decrease the value of α_2 in decision making. Tables 10 and 11 show the results of decision making when α_2=20 (good situation-Table 10) and α_2=8 (bad situation-Table 11) and other α_i=13.81. It is noticed that in better situation of fuzzy resource better results would obtain.

So in this method the decision maker input α_i experimentally and obtains optimal values for decision variable consider to get maximize values for objective functions with providing a better level of satisfaction.

Table 10: Solution found from DFLP model

z_1	z_2	z_3	x_1	x_2	x_3	μ
27068	22293	19858	570	1055.5	875.6	0.84

Table 11: Solution found from DFLP model

z_1	z_2	z_3	x_1	x_2	x_3	μ
26608	21930	19518	558.6	1046.7	858	0.15

Figure (4) shows the objective function in terms of μ_0 and μ_b for α_2=20 and other α_i=13.81 and figure (5) shows the objective function in terms of μ_0 and μ_b for α_2=8 and other α_i=13.81.

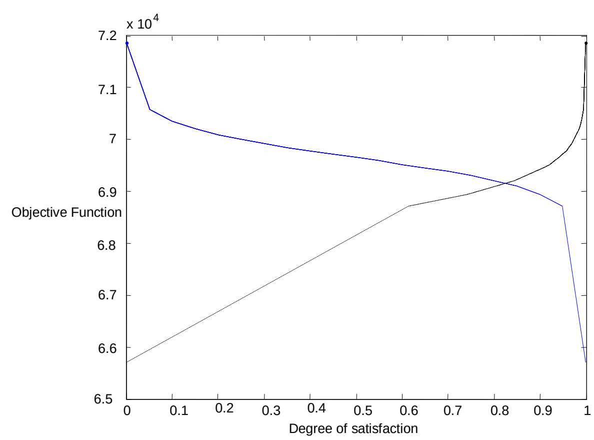

Figure (4): objective function in terms of μ_0 (--), μ_b (-) for α_2=20 and other α_i=13.81

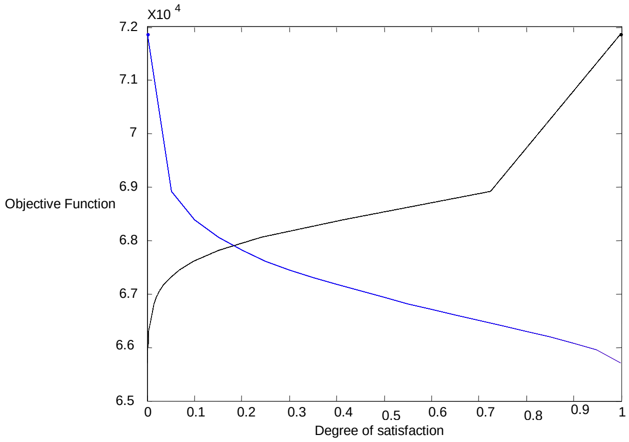

Figure (5): objective function in terms of μ_0 (--), μ_b (-) for α_2=8 and other α_i=13.81

4. Conclusions

Planning process for supporting engineering and construction industry activities facing with uncertain data and dynamic environment and heuristic judgment. DFLP model could be useful to overcome these problems. The result of this paper clearly indicates superiority of the DFLP model approach. This methodology is recommended in dynamic environment and where the decision maker wishes to apply his strategy to planning and programming problem at right time.

This methodology is also very flexible and could be used in any industry activities. Further research will be directed on using this model in other engineering activities like project scheduling and analyzing the project performance results.

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