Improvement of Productivity by using Fuzzy Mathematical Tool

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ABSTRACT

The term productivity is concerned with the efficient utilization of resources in producing goods and/or services. There are several productivity improvement techniques. The problem is to select proper technique at proper time with-in several constraints. Different models such as Goodwin's model, Sutermeister's model, Hershauer and Ruch's model etc. have been developed, out of which Analytical Productivity Improvement Technique is the best suited because it considers several parameters and gives better results, than other. But this model is unable to solve multi-objective problem. This model also considers rigid value of parameter. In real world problem, various parameters such as material cost, labour cost, investment, total cost/unit, profit etc. may be flexible with vagueness in their value. All these parameters are normally variable and imprecise. Due to imprecise nature of the parameter the problem becomes fuzzy. Here a fuzzy multi-objective programming model is proposed for productivity improvement. In real life all the goals are not of equal importance, therefore normalized weight have been assignment to various goals. A mathematical model has been developed by using normalized weights under fuzzy environment.

1. ANALYTICAL PRODUCTIVITY IMPROVEMENT MODEL (APIM) [15]

A six step procedure is proposed for improving the total productivity of an organization based on an analytical model;

(i) Data Collection

A two types survey questionnaire is used to collect two types of information from an organization;

(a) Total sales and total expenses for several time periods in the past (the time periods can be months, quarters, half-years, etc.). These are used as estimates of total output and total input, respectively.

(b) Productivity improvements techniques uses in the corresponding time periods.

The first type of information's comes readily from the financial statements, while the second type of information is available from industrial engineering or operation departments.

(ii) Computation of Productivity Changes And Data File Compilation:

The next step is to calculate the percentage change in total productivity between consecutive time period t and t-1

$$PC_t = \frac{TP_t - TP_{t-1}}{TP_{t-1}} X\ 100$$

Where PC_t = Percent change in total productivity between t-1 and t

TP_t = Total productivity at time t

TP_{t-1} = Total productivity at time t-1

The total output and total input are expressed is constant with respect to a based period.

(iii) A data file structure is then prepared, showing the percent change in total productivity and the technique of productivity improvement used in the various time periods. We denote the K^{th} technique by T_k, where k= 1,2,........K (K=54, according to our classification).

(iv) Determination of Productivity improvement Coefficient:

Assuming that there is a linear relationship between the change in total productivity and the uses of the productivity improvement techniques in a given period, we can express PC_t as follows

$$PC_t = A_{0t} + A_{1t}\ T_{1t} + A_{2t}\ T_{2t} + A_{3t}\ T_{3t} + \ldots\ldots\ldots + A_{kt}\ T_{kt} + A_{54t}$$

$$\text{Where } T_{kt} = \begin{cases} 1 & \text{if technique k is used in period t} \\ 0 & \text{otherwise} \end{cases}$$

(v) Evaluation of the productivity Improvement coefficients and Technique Uses:

Those techniques that are associated with negative productivity improvement coefficients may be noted in order to determine the reasons for their not contributing to the organization's total productivity.

A frequency distribution of the usage of the techniques for different time periods is also prepared in order to indicate the consistency with which some of these techniques have been yielding positive productivity changes.

The techniques that are associated with positive coefficients are selected as a preliminary set; we shall call these the “candidate Techniques”, subjected to a quantitative analysis in the next step.

(vi) Selection of Techniques For Productivity Improvement:

A final selection of the techniques for productivity improvement is made by forming an integer programming model for a given time period.

2. MODEL FORMULATION (SIMPLE ADDITIVE MODEL FOR MULTI-OBJECTIVE PRODUCTIVITY IMPROVEMENT TECHNIQUES-MPIT):

A linear model for multi-objective productivity improvement techniques (MPIT) having 'k' objective 'n' variables subject to 'm' constraints is being formulated as :

Optimize $\{f_1(x), f_2(x), \text{----------}, f_k(x)\}$

Subject to $g_j(x) \leq$ or $\geq b_j$, $j = 1,2,3, \ldots\ldots\ldots\ldots., m$

$X = (x_1, x_2, x_3, \text{------------}, x_n) \geq 0$ (eqa. 2.1)

Where $f_1(x)$, $f_2(x)$, ----------, $f_k(x)$ denote various costs and $g_1(x)$, $g_2(x)$,-------,$g_m(x)$ are the constraints related to the system.

Aspiration level vectors p_i to the k objectives $f_i(x)$, (i= 1,2, ---------, k) which gives rise to the following problem known as multi-objectives $f_i(x)$, (i= 1,2,……, k). Then the model (eqa. 2.1) is stated as

Determine x,

Subject to $f_i(x) \leq$ or $\geq p_j$, $i = 1,2, \ldots\ldots\ldots\ldots., k$

$g_i(x) \leq$ or $\geq b_j$, $j = 1,2, \ldots\ldots\ldots\ldots., m$

$x \geq 0$ (eqa. 2.2)

In real situation, rigid goal vector $P = (p_1, p_2, \ldots\ldots\ldots p_k)$ and $B = (b_1, b_2, \ldots\ldots\ldots b_m)$ don't exist. Let us assume that all goal be fuzzy, therefore, it is more realistic to assign fuzzy goals by allowing some flexibility in the right hand side of all goals [10]. Now the fuzzified version of this model [21] is

$f_i(x) \leq \sim$or $\geq \sim p_j$, $i = 1,2, \ldots\ldots\ldots\ldots., k$

$g_i(x) \leq \sim$ or $\geq \sim b_j$, $j = 1,2, \ldots\ldots\ldots\ldots., m$

$x \geq 0$ (eqa. 2.3)

Where, the wavy symbol (~) stands for fuzzification (approximation).

We allow each p_i of vector P to go above p_i, say to p_i', and each elements b_j of vector B to go above b_j say b_j'. Here 'α_j' & 'β_j' are tolerance limits.

The model (eqa.2.3) cannot be solved in the present form. Therefore we defuzzify this model with the help of linear membership function [31] as discussed below.

$$\mu f_i\,(x) = \frac{p_i' - f_i\,(x)}{\alpha_i} \text{ or } \frac{f_i\,(x) - p_i'}{\alpha_i} \qquad i = 1,2,3, \ldots\ldots\ldots\ldots\ldots\ldots, k$$

$$\&\ \mu g_j\,(x) = \frac{b_j' - g_j\,(x)}{\beta_j} \text{ or } \frac{g_j\,(x) - b_j'}{\beta_j} \qquad j = 1,2,3, \ldots\ldots\ldots\ldots\ldots\ldots, m$$

The overall achievement function is taken as algebraic sum of all membership functions.

The additive fuzzy linear programming model of MPIT problem using additive operator can be given by:

$$\text{Max. V}\,(\mu) = \sum_{i=1}^{k} \mu f_i\,(x) + \sum_{j=1}^{m} \mu g_j\,(x)$$

Subject to : $\alpha_i \mu f_i(x) + f_i\,(x) = p_i'$, or $f_i\,(x) - \alpha_i \mu f_i(x) = p_i'$, $i = 1,2 \ldots\ldots,k$

$\beta_j \mu g_j(x) + g_j\,(x) = b_j'$, or $g_j\,(x) - \beta_j \mu g_j\,(x) = b_j'$, $j = 1,2 \ldots\ldots,m$

$x \geq 0$ (eqa. 2.4)

This model is solved by Simplex algorithm.

The additive fuzzy linear programming model of MPIT problem provides the solution of the model (eqa.2.1) but in real life all the goals are not of equal importance i.e. they are of different importance. So normalized weights must be used to assign the various goals.

We assign w_1, w_2, w_3 ......, w_k, ... w_{k+1}, w_{k+2}, ... w_m to fuzzy goals respectively.

Therefore the weighted additive fuzzy linear programming model of MPIT problem can be stated as

$$\text{Max. } V(\mu) = \sum_{i=1}^{k} w_i \mu f_i(x) + \sum_{j=1}^{m} w_{k+j} \mu g_j(x)$$

Subject to: $\alpha_i \mu f_i(x) + f_i(x) = p_i'$, or $f_i(x) - \alpha_i \mu f_i(x) = p_i'$, $i=1,2 \ldots\ldots, k$

$\beta_j \mu g_j(x) + g_j(x) = b_i'$, or $g_j(x) - \beta_j \mu g_j(x) = b_j'$, $j = 1,2 \ldots\ldots, m$

$w_1, w_2, w_3 \ldots\ldots, w_k, \ldots\ldots w_{k+1}, w_{k+2}, \ldots\ldots w_{k+m} \geq 0,$

$w_1, + w_2, + \ldots\ldots + w_k + w_{k+1}, + w_{k+m} = 1,$

$x \geq 0$ (eqa. 2.5)

This is solved by simplex algorithm.

In APIM all the parameters have been considered rigid [15]. But practically this is not feasible. Therefore we have these parameters like productivity improvement coefficient, annual budget, annual savings, etc. as flexible. The model formulated in fuzzy form is as follows,

Determine T_K

Such that:-

$$f_1(T_k) \sum_{k=1}^{r} A_k T_k \geq \sim p_i$$

$$g_1(T_k) = \sum_{k=1}^{r} f_k T_k \leq \sim F$$

$g_2(T_k) =$ $b_k T_k \leq \sim B$ for $k = 1, 2, \ldots\ldots\ldots\ldots\ldots r$

$g_3(T_k) =$ $m_k T_k \leq \sim M$ for $k = 1, 2, \ldots\ldots\ldots\ldots\ldots r$

$$g_4(T_k) = \sum_{k=1}^{r} S_k T_k \leq \sim S$$

$T_k = 0, \ 1,$ (eqa. 2.6)

$$\text{Where } T_k = \begin{cases} 1 & \text{if technique k is selected} \\ 0 & \text{otherwise} \end{cases}$$

A_k = Productivity improvement coefficient for technique K.

f_k = fund requirement for technique K.

F = maximum available funds.

b_k = payback period for technique K.

B = maximum allowable payback period as per organizational policy

m_k = time required to install technique K

M = maximum allowable installation time.

S_k = Savings from using technique K.

r = number of candidate techniques.

S = minimum acceptable total savings

3. CASE STUDY

The data collected from **JMT Auto Limited, Jamshedpur**. Let us assume that company wants to know which techniques it should implement to obtain the maximum gain in total productivity, given that the maximum annual budget is Rs. 2.31 crores and requires the minimum annual saving of Rs. 2.82 crores. Looking at the payback period in table 1, that they are quite satisfactory and that no specific time limits need to be imposed.

Table-1 : Practical Data

	Technique	Improvement coefficient	Average payback period time (months)	Average annual savings attributable to the technique (in Rs. crores)
T_1	Production scheduling	22.79	4.6	2.36
T_2	Communication	98.16	4.0	2.52
T_3	Job evaluation	13.39	3.0	0.75
T_4	Energy conservation	48.51	3.0	1.51
T_5	Individual	6.42	1.0	0.001

	financial incentive			

Using the data from above the table 1a, the formulation of final selection of the productivity improvement techniques from among the candidate techniques is given by the following:

Maximize $f_1(T_k) = 22.79T_1 + 98.16T_2 + 13.39T_3 + 48.51T_4 + 6.42T_5$

Subject to $g_1(T_k) = 2.36T_1 + 2.52T_2 + 0.75T_3 + 1.51T_4 + 0.001T_5 > 2.82$

$g_2(T_k) = 0.905T_1 + 0.84T_2 + 0.1875T_3 + 0.3775T_4 + 0.000083T_5 \leq 2.31$

$T_k = 0,1$ for $k = 1, 2, 3, 4, 5$ (eqa. 3.1)

This model is solved using mixed integer programming on LINDO software.

The solution obtained is given in table 1

$T_1 = 1$, $T_2 = 1$, $T_3 = 1$, $T_4 = 1$, $T_5 = 0$, objective function value = 182.85

Table 2: Final selection of productivity improvement techniques

Available budge (crores)	Solution					Objective function
	T_1	T_2	T_3	T_4	T_5	
2.25	1	1	0	1	1	175.88
2.26	1	1	0	1	1	175.88
2.27	1	1	0	1	1	175.88
2.28	1	1	0	1	1	175.88
2.29	1	1	0	1	1	175.88
2.30	1	1	0	1	1	175.88
2.31	1	1	1	1	0	182.85
2.32	1	1	1	1	1	189.27
2.33	1	1	1	1	1	189.27
2.34	1	1	1	1	1	189.27

2.35	1	1	1	1	1	189.27

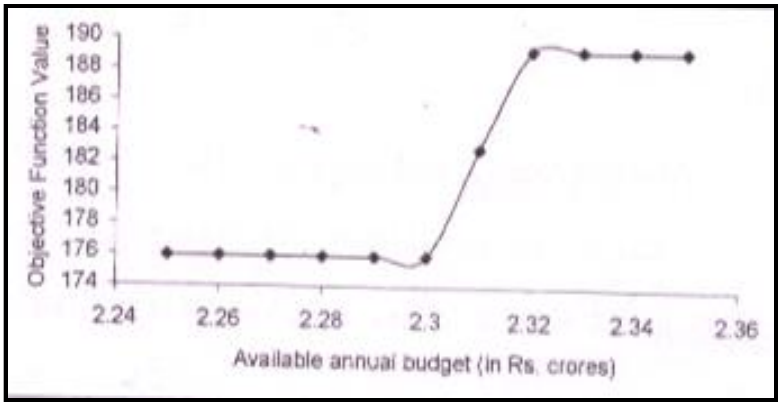

Fig.1 shows the graph between Available annual budget and Objective function value

- T_1 = production scheduling; T_2 = communication; T_3 = job evaluation;
- T_4 = energy conservation; T_5 = Individual financial incentives.

The fuzzy version of the above problem can be set as :

Determine T_k

Such that: $f_1(T_k) = 22.79T_1 + 98.16T_2 + 13.39T_3 + 48.51T_4 + 6.42T_5 \geq\sim 200$

$g_1(T_k) = 2.36T_1 + 2.52T_2 + 0.75T_3 + 1.51T_4 + 0.001T_5 \geq\sim 2.82$

$g_2(T_k) = 0.905T_1 + 0.84T_2 + 0.1875T_3 + 0.3775T_4 + 0.000083T_5 \leq\sim 2.31$

$T_k = 0,1$ for $k = 1,2,3,4,5$ (eqa. 3.2)

Now the problem is defuzzified as follows:

The linear membership functions corresponding to these fuzzy goals are defined as:

$\mu f_1(T_k) = \frac{f_1(T_k)-170}{30}$, $\mu g_1(T_k) = \frac{g_1(T_k)-2.52}{0.30}$,

$$\mu g_2(T_k) = \frac{2.16 - g_2(T_k)}{0.25},$$

$\alpha_1 = 30$, $\beta_1 = 0.3$, $\beta_2 = 0.25$

The crisp model is given by

Max. $V(\mu) = \mu f_1(T_k) + \mu g_1(T_k) + \mu g_2(T_k)$

Subject that :

$22.79T_1 + 98.16T_2 + 13.39T_3 + 48.51T_4 + 6.42T_5 - 30\,\mu f_1(T_k) = 170$

$2.36T_1 + 2.52T_2 + 0.75T_3 + 1.51T_4 + 0.001T_5 - 0.3\,\mu g_1(T_k) = 2.52$

$0.905T_1 + 0.84T_2 + 0.1875T_3 + 0.3775T_4 + 0.000083T_5 + 0.25\,\mu g_2(T_k) = 2.16$

$T_k = 0,1$ for $k = 1,2,3,4,5$ (eqa. 3.3)

Table -3 : Selection of Productivity Improvement Techniques.

Objective function	Annual saving (in Rs. crores)	Annual budget (in Rs. crores)	α_1	β_1	β_2	P'_1	b'_1	b'_2	Solution				
									T_1	T_2	T_3	T_4	T_5
16.08533								2.32	1	1	1	1	1
16.12533								2.33	1	1	1	1	1
16.16533								2.34	1	1	1	1	1
16.20533								2.35	1	1	1	1	1
16.24533								2.36	1	1	1	1	1

This problem may be written in weighted additive fuzzy linear programming model of MPIT is

Max. $V(\mu) = 0.7\,\mu f_1(T_k) + 0.2\,\mu g_1(T_k) + 0.1\,\mu g_2(T_k)$

Subject to :

$22.79T_1 + 98.16T_2 + 13.39T_3 + 48.51T_4 + 6.42T_5 - 30\mu f_1(T_k) = 170$

$2.36T_1 + 2.52T_2 + 0.75T_3 + 1.51T_4 + 0.001T_5 – 0.3\,\mu g_1(T_k) = 2.52$

$$0.905T_1 + 0.84T_2 + 0.1875T_3 + 0.3775T_4 + 0.000083T_5 + 0.25\ \mu g_2 (T_k) = 2.16$$

$$T_k = 0,1 \quad \text{for } k = 1,2,3,4,5 \qquad \text{(eqa. 3.4)}$$

Table –4 : Final selection of productivity improvement techniques.

Objective function	Annual saving (in Rs. crores)	Annual budget (in Rs. crores)	α_1	β_1	β_2	p_1	b_1	b_2	Solution				
									T_1	T_2	T_3	T_4	T_5
2.720834	2.82	2.31	30	0.3	0.25	170	2.52	2.13	1	1	0	1	1
2.724833								2.14	1	1	0	1	1
2.728833								2.15	1	1	0	1	1
2.732833								2.16	1	1	0	1	1
2.736833								2.17	1	1	0	1	1
2.740834								2.18	1	1	0	1	1
2.744833								2.19	1	1	0	1	1
2.748833								2.20	1	1	0	1	1
2.752833								2.21	1	1	0	1	1
2.756833								2.22	1	1	0	1	1
2.760834								2.23	1	1	0	1	1
2.764833								2.24	1	1	0	1	1
2.768833								2.25	1	1	0	1	1
2.772833								2.26	1	1	0	1	1
2.776833								2.27	1	1	0	1	1
2.780833								2.28	1	1	0	1	1
2.784833								2.29	1	1	0	1	1
2.788833								2.30	1	1	0	1	1
3.379833								2.31	1	1	1	1	0
3.534267	2.90	2.50						2.32	1	1	1	1	1
3.538267								2.33	1	1	1	1	1
3.542267								2.34	1	1	1	1	1
3.546267								2.35	1	1	1	1	1
3.550267								2.36	1	1	1	1	1

4. RESULT AND DISCUSSION

i) The result obtained by existing method were based on single objective only where as the results of the adopted method have been drawn from multiple objectives.

ii) Accordingly a lot of good results have been obtained by little variation in available annual budget of Rs. 0.19 crores. Decision maker, who has to take decision in changing circumstances, may be in a position to take variable decisions to suit the industrial requirement.

iii) For the budget of Rs. 2.31 crores, the production manager may recommend installing four new techniques for improving total productivity of the industries, i.e. production scheduling, communication, job evaluation, and energy conservation. Consequently, this depends upon the decision maker, which solution is best suited to him.

iv) For the budget of Rs. 2.50 crores decision maker can implement individual financial incentive as well as annual saving many also increases Rs. 0.08 crores, which will improve the employee's moral.

v) Finally, the total productivity may be improved by small increment in flexibility in time. In addition to this, all the techniques can be implemented successfully on the same budget, if there may a provision of little more time.

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