EFFECTIVE TOOL FOR FUNCTIONAL EVALUATION OF INTRICATE CASES IN CONSTRUCTION PROJECTS

Manoj Kulshrestha, ME, Lecturer, IGNOU, New Delhi, INDIA
Dr. V. B. Deshpande, Ph.D., Associate Professor, IIT, New Delhi, INDIA

Manoj Kulshrestha, ME in Construction Management, is a lecturer at Indira Gandhi National Open University (IGNOU), New Delhi, INDIA where he teaches construction management in Bachelor programme through distance mode. He has completed his research work and submitting his thesis shortly for his doctoral degree at Indian Institute of Technology; New Delhi. His area of research is "Multile Criteria Decision Making applied to Construction Management".He has been a member of SAVE since 1993, he is also the Joint Secretary of Society of Indian Value Management (with a Master's SIVAM), Delhi Branch.

Dr. V. B. Deshpande with Ph.D. from University of Liverpool, UK, is working as Associate Professor in the Deptt. of Civil Engineering at Indian Institute of Technology, New Delhi, INDIA. He introduced Value Engineering (VE) as a subject to graduate students and has been teaching the course for the last 14 years. He has guided several projects in VE and other related subjects of construction management. He has conducted a number of consultancies/workshops/short term courses in VE for professionals and teachers. He was the Technical Editor for the International Conferences on VE held in 1991 and 1993 at New Delhi.

ABSTRACT

The interdependent and multifunctional nature of various components/elements of a construction project in civil engineering makes the process of comparison of functions very difficult in numerical evaluation technique with a limited choice of weight factors. The paper presents a matrix based methodology with larger numerical scale. A simple geometric mean approximation approach has been adopted for computing the eigenvector of square decision matrix, which in turn, gives the Priority Vectors (PV) on normalisation.

INTRODUCTION

The importance of function in VE management can be realised through the following frequently used statements :
"VE is a function oriented approach",
"Function is a cornerstone of VE",
"Function is the heart of VE".

In the light of above statements, it is of utmost importance to identify and evaluate the functions of any product, system, process or procedure precisely and then, correctly evaluate them for primary function(s) and secondary function(s). During the Functional Evaluation process, the problems to be tackled are:

(1) How can we represent a function by a meaningful number indicating its contribution to the overall utility to the system ?
(2) How large is the contribution of this function related to all others ?
(3) How does the individual function combine into an overall system ?

Here, in this study, a decision matrix based eigenvector approach of Analytical Hierarchy Process has been presented to solve the above mentioned problems of functional evaluation.

This method is suitable to handle the complex cases in civil engineering construction as well as in other related fields of engineering. In situation, where each function sounds in equal degree of importance, it has been found very useful technique to label the functions as basic or secondary. This method is capable of comparing and evaluating the identified functions and determine their inter-relationship along with the order of their relative importance to the whole. This order of relative importance of various functions and their inter-relationship, derived on the basis of PV of each function, makes it possible for us to study the results and draw specific contributions on our problem's complexity.

A REVIEW OF NUMERICAL EVALUATION TECHNIQUE

The numerical evaluation technique is accomplished with the use of tabular format given in Figure 1.0. The comparison and evaluation process of numerical evaluation technique requires a thorough understanding of the facts, data and information secured in the Information Phase. This technique mainly has following two parts :

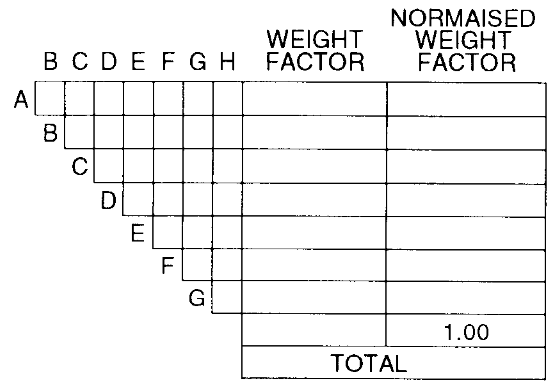
(1) Comparison and evaluation
(2) Summation

Comparison and evaluation

The comparison and evaluation part of this technique is started by relating function A to function B and determining which is more important. The key letter of function, appears to be more important, is placed in the upper-left-hand box i.e. AB box (Figure 1.0). The difference in importance of the function is signified by the weight factors 1, 2 and 3 which indicate a minor, medium and major difference of importance respectively. Function A is compared and evaluated with function B and key letter of the more important function is entered, alongwith its weight factor in the appropriate box. The comparison and evaluation process is then continued by relating function B to each of the remaining functions and placing the results in the respective boxes of the second row. The procedure is repeated, taking one function at a time with the remaining functions. This comparison and evaluation process is continued until every function has been individually compared and evaluated with every other function.

Summation

After the weighted comparison and evaluation has been made for each function relative to every other function, a summation of these can be compiled. This summation is accomplished by adding the weight factors, both horizontally and vertically, for each function's key letter and placing the total in the weight factor column on the same line of the key letter. After obtaining the weight factors for all the functions, they are normalised to unity. From a comparison of the normalised values in the weight factor column, the basic function is readily verified. This will be the function with the highest weight factor. The secondary functions and their descending order of importance are also determined by comparison of each function's weight factor totals.



NUMERICAL EVALUATION FORMAT

1 = Minor Difference of Importance
2 = Medium Difference of Importance
3 = Major Difference of Importance

Figure 1.0

DECISION MATRIX APPROACH

The decision matrix analysis, carried out for functional evaluation in the Functional Phase is accomplished using the worksheet titled Functional Evaluation Sheet. The proforma of Functional Evaluation Sheet has been presented in Appendix 'A'.

In functional evaluation, various functions are compared to each other for evaluating their relative importance. This comparison and evaluation process demands a thorough knowledge and understanding of the project or system in question. This is necessary because in the comparison and evaluation of the functions, a bit of subjectivity based on this information has to be applied. The facts and data related to the project and its elements, collected in the Information Phase help in the pairwise comparison of the functions. This technique is essentially applied through following steps :

(A) Construction of Square Decision Matrix
(B) Analysis of Consistency in Decision Making
(C) Computation of PV

(A) Construction of Square Decision Matrix

Firstly, the list of all identified functions is placed in the appropriate section entitled "evaluation summary" in the worksheet (Appendix A). Each of the functions in the list on the functional evaluation sheet is assigned a key letter. This key letter is used throughout the comparison and evaluation process of the functions. The pairwise comparison procedure is started by relating function A on the left to the function B on the top of the matrix and determining which is more important. If function A seems to be more important than B, then a suitable integer value from the Table 1.0 is entered in the box of functional evaluation matrix. If function A appears to be less important than B, then the reciprocal of previous integer value is used. Thus, in this technique, two entries are made simultaneously with one judgement i.e. one integer and its reciprocal at mutually transposed positions. When a function is compared with itself, the unit weight factor is entered in the decision matrix. That is why, left to right diagonal of the matrix always has unit entries. In this way, only n(n-1)/2 judgements have to be taken to complete the decision matrix where n is the number of functions to be analysed. This procedure is repeated by comparing one function on the left at a time, with all the remaining functions on the top of the matrix.

Pairwise comparison of functions is easier than the assigning all the weights simultaneously. It is based on the idea that a complex issue can be effectively examined if it is hierarchically decomposed into the parts. The functions are compared with each other and thus, providing us an opportunity for evolving the structure into an (n x n) reciprocal square decision matrix. Thus, by pairwise comparison of functions, a square decision matrix is constructed by entering appropriate weight factors from the Table 1.0.

Table 1.0

SCALE OF RELATIVE IMPORTANCE IN DECISION MATRIX APPROACH

Intensity of relative importance(s)	Definition	Explanation
1	Equally important functions	Two functions contribute equally to the value
3	Moderate importance of one function over another	Experience & judgement slightly favours one function over other
5	Essential or strong importance	Experience & judgement strongly favours one function over other
7	Demonstrated importance	A function is strongly favoured & its dominance is demonstrated in practice
9	Extreme importance	The evidence favouring one function over other is of highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgements	When compromise is needed
Reciprocal of above non-zero numbers	If a function is given one of the above numbers when compared with a second function, then the second function is assigned the reciprocal value when compared with the first function.	

determinant of Equation (2) must vanish. Thus,

$$\begin{vmatrix} 1-\lambda & 2.0 \\ 0.5 & 1-\lambda \end{vmatrix} = 0 \quad \text{i.e. } (1-\lambda)^2 - 1 = \lambda^2 - 2\lambda = 0.$$

It shows that the Equation (2) provides a non-zero solution for only two values of λ i.e. 0 and 2. These two values 0 and 2 are said to be the **eigenvalues** of the matrix A.

Let us find out the corresponding eigenvector. For the value 0 of λ, Equation (2) reduces to

$$x_1 + x_2 = 0$$

whose solution is a set of vector $X = (x_1, x_2)^T = (\lambda, -\lambda)^T$ for any arbitrary value of $\lambda \neq 0$.

We can say that for the eigenvalue 0, there is only one linearly independent eigenvector. This eigenvector can be picked up to be any one of the set of vectors $(\lambda, -\lambda)^T$, say for the example $(1, -1)^T$ or $(-5, 5)^T$.

For the value 2 of λ, Equation (2) reduces to,

$$-x_1 + x_2 = 0,$$

which permits the vector $(\beta, \beta)^T$, $\beta \neq 0$ as a solution. We can, as before, say that $X = (1, 1)^T$ is an eigenvector corresponding to the eigenvalue 2.

(3) PV

A PV can be defined as a simple normalised eigenvector corresponding to greatest non-zero eigenvalue of a square decision matrix. In fact, it is a column matrix of order n by 1 and whose elements/components add to unity.

Now, it can be shown mathematically that a priority eigenvector corresponding to the greatest non-zero eigenvalue of the decision matrix is a cardinal ratio scale for the functions compared if the decision maker (DM) is consistent in his judgements.

To show this, let us assume that there exists a theoretical scale of importance for each function.

Let this scale be $w_1, w_2, w_3, \ldots, w_n$.

We now construct the theoretical pairwise comparison matrix M whose elements in the ith row and jth column is w_i/w_j, where w_i and w_j are the exact weights of the functions i and j respectively. The matrix M is shown below.

$$M_{(n \times n)} = \begin{bmatrix} w_1/w_1 & w_1/w_2 & . & . & . & w_1/w_n \\ w_2/w_1 & w_2/w_2 & . & . & . & w_2/w_n \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ w_n/w_1 & w_n/w_2 & . & . & . & w_n/w_n \end{bmatrix}$$

Let the column vector of weight factors $(w_1, w_2, w_3, \ldots, w_n)^T$ is denoted by $w_{(n \times 1)}$.

Performing the operation Mw yields a column vector,

$$Mw = (nw_1, nw_2, nw_3, \ldots, nw_n)^T$$

or $Mw = n(w_1, w_2, w_3, \ldots, w_n)^T = nw$

or $M(n \times n)\ w_{(n \times 1)} = nw_{(n \times 1)}$ ...(3)

Equation (3) is the eigen-equation of the matrix M.

On comparing Equation (3) with Equation (1), we get,

$$n = \lambda$$

This result shows that n (total number of functions compared) is an eigenvalue of matrix M and w is the corresponding eigenvector. Since the matrix M is of rank 1, it has total (n - 1) eigenvalues which are zero and one non-zero eigenvalue which is equal to n, the order of the matrix M. Therefore, the greatest eigenvalue of matrix M, i.e., $\lambda_{max} = n$.

The above relationship can be verified from the result of the example given in the previous section. Since, a matrix of order 2 has been analysed here, it is evident that there is only one non-zero eigenvalue which is equal to 2 i.e. $\lambda max = n =$ order of the matrix. A eigenvector corresponding to greatest eigenvalue

2

2 is computed as $X = (1,1)^T$. On normalisation of the resulting vector to unity or 100%, a column vector $X = (0.5, 0.5)^T$ is derived which is PV.

(B) Analysis of Consistency in Decision making

In the previous section, it has been shown that,

$$\lambda_{max} = n$$

where n is the order of the square decision matrix.

This result is valid only when the decision maker is consistent in his judgements. On the other hand, in real life, perfect consistency is hard to live up to.

The deviation of the λ_{max} from n is regarded as the measure of inconsistency in judgements. Now, let the matrix A be the decision maker's emperical estimate of matrix M. Thus, emperical decision matrix A ideally should satisfy certain relationship, viz., if the ith function is twice as important as jth function and the jth is thrice as important as kth one, then ith function should be six times as important as the kth one. λ Mathathematically can be expressed as,

$$a_{ij} \cdot a_{jk} = a_{ik} \qquad \text{for all i, j and k.}$$

The value n is the principal eigenvalue of matrix A in case of perfect consistency. If A is slightly inconsistent, λ_{max} will also slightly deviate from n on the higher side. Therefore, the closer λ_{max} is to the order n,λ# the greater is the consistency exhibited by the matrix. In order to measure the relative consistency, a Consistency Index (C.λ.) for a single matrix is introduced as,

$$C.I. = \frac{(\lambda_{max} - n)}{(n - 1)}$$

For a reciprocal matrix, $\lambda_{max} > n$ always.

A Random Index (R.I.) is defined as a C.λ of a randomly generated reciprocal matrix. For different order matrices, the corresponding random consistency has been presented in Table 2.0.

Finally, a Consistency Ratio (C.R.) is defined as

$$C.R. = \frac{\text{Consistency Index (C.I.)}}{\text{Random Index (R.I.)}}$$

The value of C. R. should be within 10% for good results, but generally, for functional evaluation, the limit up to 15% may be accepted. In case the C. R. is higher than the limit, then decision makers of VE team should consider for revising their judgements.

(C) Computation of Priority Vector

The square decision matrix on its analysis gives a way to determine qualitatively the relative importance of functions in a problem situation. After obtaining the decision matrix, it is suitably

analysed to compute the vector of priorities or

P.V.. In terms of matrix alzebra, the decision matrix

Table 2.0

RANDOM CONSISTENCY

Size of Matrix	1	2	3	4	5	6	7	8	9	10
Random Consistency	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

analysis consists of determining the P.V.(eigenvector) of the matrix and then normalising it to 1.0 or 100% to obtain the PV.

A computer program has also been developed in FORTRAN 77 language for computing the PV. The programe computes PV, principal eigenvalue (λ_{max}), C.I.and C.R. Manual computation of the eigenvectors of a matrix is not very difficult but can be time consuming for the higher order matrices. Therefore, analysis of decision matrix is carried out by some approximation methods which are good to provide sufficiently close results for application. Geometric mean approximation method to compute PV has been presented below.

Geometric mean approximation method

In this approximation procedure, the geometric mean of the elements in the each row is computed. For this, all the elements in the row are multiplied and then its nth root is taken. This step is followed by normalising the resulting vector so that its elements adds to unity or 100%. This forms the column of PV. In general, the geometric mean approach is a good approximation particularly when the consistency is high.

Determination of lmax

Firstly, totals of each column are determined. Then, sum of each column of decision matrix is multiplied with corresponding priority vector i.e. sum of column 1 with components of priority vector for row 1 and so on. The sum of the products so obtained is called maximum or principal eigenvalue (λ_{max}).

By the inspection of the column of components of the PV, the basic function(s) is readily determined. This will be the function with the highest component of PV. Sometimes, there may be more than one basic function also. The basic function(s) and some other important secondary functions are distinctly identified through this technique which guide the accomplishment of succeeding phases of VE job plan.

In the next step, the C.I. is calculated and this C.I. is compared with the random consistencies of same order matrix to get the C.R. which is finally a measure of degree of consistency of decision maker.

CONCLUSIONS

The functional evaluation study by decision matrix analysis through eigenvector approach helps in identifying the basic function(s) and some other important secondary functions. Identification of important secondary functions helps in forming the functional attributes for VE implementation through Multple Criteria Decision Making techniques.

This proposed technique follows a nine-point scale from 1 to 9 as compared to normal scale used from 1 to 3 in conventional numerical evaluation technique. Thus, it offers a wide range of choice for decision makers to give their judgements. In this method, the decision matrix follows a square matrix and advantage is taken of the properties of eigenvalues and eigenvectors of a square matrix to check the consistency of the judgemental values assigned to various elements in the decision matrix. The concept of C.R. also makes the judgements in functional evaluation more scientific & rational because we may not desire VE to be based on judgements that has such a low consistency that they appear to be random. It also gives the decision maker the scope for revising and improving the judgements.

Further, for analysis of results, all the functions can be listed in their descending order of importance according to their value of PV components. On plotting the decending order of the functions against their PV components, it provides an additional and significant information about the potential areas in the system or product for the application of VE technique.

REFERENCES

(1) Saaty, Thomas L. (1980), *The Analytical Hierarchy Process*, McGraw-Hill Book Company.

(2) Mudge, E. Arthur, *VE - A Systematic Approach*, J. Pohl Associates, 1706 Berkwood Drive, Pittsburg PA.

(3) Saaty, Thomas L. (1982), *Decision Making for Leaders*, Lifetime Learning Publications, Division of Wardsworth Inc., Belmont, California.

(4) Kulshrestha, Manoj et al. (1993), "Multi Criteria Decision Theory : An Effective Tool for VE Implementation", *Proceedings of International Conference of ACCE and SIVAM*, New Delhi, p. 119-128.

(5) Ghosh, Prabir (1991), "Function : the heart of VE", *Proceedings of International Conference of SIVAM*, New Delhi, p. 95-97.

(6) Mario, T. Tabucannon, *Multi Criteria Decision Making for Industry*, Elsevier Publishers.

(7) Zimmerman, L.W. and Hart G.D., (1988), *VE - A Practical Approach for Owners, Designers and Contractors*, CBS Publishers & Distributors, New Delhi.

APPENDIX 'A'

FUNCTIONAL EVALUATION SHEET

EVALUATION SUMMARY

KEY LETTER	FUNCTIONS		PRIORITY VECTOR	RANK	SYMBOLIC GRADE
	VERB	NOUN			
A					
B					
C					
D					
E					
F					
G					
H					

FUNCTIONAL EVALUATION

λ_{max} =
C.R. =

	A	B	C	D	E	F	G	H	EIGEN VECTOR COMPONENT OF ROWS	PRIORITY VECTOR
A	1									
B		1								
C			1							
D				1						
E					1					
F						1				
G							1			
H								1		
TOTAL OF COLUMNS										1.00

NAME OF THE VE TEAM MEMBER :

SPECIALISATION :

DATE :

(SIGNATURE)

PROJECT :

ITEM :

DRAWING NO. :