

Development of Multiple Criteria Decision Support System (MCDSS) for Value Management Implementation in Construction Projects

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ABSTRACT

The application of Value Management (VM) in construction, sometimes, becomes a complex decision process if various value alternatives identified during the creative and analytical phase, differ with respect to multiplicity of attributes considered such as functional performance, cost, reliability and safety. To deal with this specific situation, the paper presents some concepts of Multiple Criteria Decision Theory (MCDT) and establishes an analogy between decision environments of VM and MCDT. Two of the MCDT techniques, namely Analytic Hierarchy Process (AHP) and Fuzzy Set Methodology (FSM) have been adopted for developing the models of Decision Support System (DSS) for incorporating MCDT in VM implementation. Accomplishment procedure and suitability of these two models in specific cases of VM implementation have also been discussed in the paper.

INTRODUCTION

Value Management (VM) is a systematic approach of obtaining optimum value for any monetary quantum spent. In this technique, through a system of investigation, unnecessary expenditure is avoided, resulting in improved value and economy. VM study is carried out through a planned procedure called "Job Plan". The job plan attempts to generate, identify and select the best value alternative(s) for making specific recommendations supported with proper data and identifying the action necessary for its implementation. In other words, through the job plan, we often develop a number of valued alternative solutions to the given problem in a value improvement project. The alternative with minimum life cycle cost is usually accepted if it satisfies all the system requirements and desired benefits. However, the decision-making process becomes too complex if various value alternatives differ with respect to multiplicity of attributes such as functional performance, cost, reliability and durability etc.

In construction projects, while implementing VM studies, the varied multiplicity of attributes affects the evaluation of value alternatives more prominently. This calls for a more scientific and innovative approach towards the implementation of VM studies in construction projects and other related fields of engineering.

In number of VM situations in construction industry, the possible consequences of the decision-making are characterised by more than a single criterion (attribute). This stage of VM decision process can be analysed as a special case of Multiple Criteria Decision Theory (MCDT). After establishing a proper analogy between VM and MCDT decision environments, it is imperative to use suitable MCDT techniques for implementing the VM studies in more realistic manner.

Some of the techniques which can be used for developing the Multiple Criteria Decision Support System (MCDSS) for any VM implementation are as follows :

- (a) Analytic Hierarchy Process (AHP),
- (b) Fuzzy Set Methodology (FSM), and
- (c) Multi-attribute Utility Theory (MAUT).

Out of these techniques, Multi-attribute Utility Theory (MAUT) is applicable in the situation when the values of the criteria (attributes) are not known with certainty and are associated with some probability, which is not the case of present VM philosophy. Moreover, it requires utility transformation function expressed graphically for every attribute, which is again a complicated and time taking process. Thus, it is not found suitable to apply for VM implementation.

This paper presents some basic concepts of Multiple Criteria Decision Theory (MCDT), and thereby developing two models of Decision Support System (DSS) in order to select the value alternative, which satisfies the combination of system requirements in the most efficient manner as desired in construction projects.

In this paper, Analytic Hierarchy Process (AHP) approach has been dealt with in detail along with brief accomplishment procedure of Fuzzy Set Methodology (FSM) in order to develop

MCDSS models. The models, thus, developed are capable of considering intangible, non-quantitative and linguistic attributes along with the quantitative and tangible attributes for the evaluation process of value alternatives during VM implementation. Finally, an attempt has also been made to establish the suitability of models for VM implementation in different situations.

MUTIPLE CRITERIA DECISION THEORY (MCDT)

A necessary condition of MCDT is the presence of more than one criterion. The sufficient condition is that the criteria must be conflicting in nature (Tabucannon, 1988). In summary, the following definition can be stated :

A problem can be considered as an MCDT problem if an only if there appear at least two conflicting criteria and there are at least two alternative solutions.

In the context of multiple-criteria decision (making) theory, if A ($a_1, a_2, a_3, \dots, a_n$) represent the different available decision alternatives and C ($c_1, c_2, c_3, \dots, c_m$) the set of criteria (attributes), then a decision matrix can be formulated as shown in Figure 1.0 where the entries v_{ij} represent the value of the (i th) alternative with respect to (j th) criterion (attribute).

		CRITERIA					
		c_1	c_2	...	c_j	...	c_m
ALTERNATIVES	a_1	v_{11}	v_{12}	---	---	---	v_{1m}
	a_2	v_{21}	v_{22}	---	---	---	v_{2m}
	...						
	a_i				v_{ij}		
	...						
a_n	v_{n1}	v_{n2}	---	---	---	v_{nm}	

Figure 1.0 : Decision Matrix for MCDT

According to MCDT, in multiple criteria decision-making (MCDM) situations, one needs a well-defined methodology and a rational scale to express decision maker's (DM's) judgements. The method should be capable of relatively comparing the criteria and alternatives through the weight factors of the fundamental scale or in other words, the method should be capable of bringing objectivity in subjective decisions.

Often in VM implementation situations, one has to take decision under the influence of more than one attribute. These attributes are, most of the time conflicting in nature. Some specific methodologies of MCDT are best suited to deal with this Multiple Criteria Decision Making (MCDM) situation.

Conflicting Criteria

Criteria are said to be in conflict if the full satisfaction of one criterion will result in impairing or precluding the full satisfaction of the other(s) criteria. In precise terms, criteria are considered to be “strictly” conflicting if the increase in satisfaction of one results in a decrease in satisfaction of the other. However, the sufficient condition of MCDT does not necessarily stipulate “strictly” conflicting criteria.

IMPORTANCE OF ATTRIBUTES IN VALUE MANAGEMENT (VM) APPLIED TO CONSTRUCTION

In construction, which is a world of conflicting criteria, the non-cost linguistic attributes often become more relevant for the proper VM implementation. For construction projects, Zimmerman (1988) also identified the importance of attributes to determine value of the product or system and recommended the following attributes for evaluating the value alternatives :

1. Initial cost
2. Profit in return
3. Reliability
4. Maintainability
5. Safety
6. Functional performance
7. Quality
8. Aesthetics and environment

It has been observed that the greatest potential for net cost saving occurs in the conception and preliminary design phases. In fact, the saving potential decreases as the project ages. Early VM study tends to produce greater savings for two reasons. First, more units are affected by saving actions; and second, earlier changes lower the implementation costs.

Thus, it can be concluded that maximum savings potential through VM in construction projects lies in conceptual stage of the project. As we are aware that every construction project is unique in nature, hence, in the conceptual stage of the construction project, VM review is conducted without any historical data or past performance analysis of the process or system in question. Under these specific circumstances, a set of attributes along with the routine functional approach of Value Management plays a vital role in selecting the most optimal value alternative(s).

Further, in presence of these important attributes, which are, most of the times, conflicting in nature, the decision process becomes more complex and difficult. The unique response of each value alternative in terms of different degree of satisfaction of various attributes makes it a distinct case of Multiple Attributes Decision Making. As a system approach, mathematical modelling through multiple criteria decision techniques is the best way to deal with this situation.

APPLICATION OF MULTIPLE CRITERIA DECISION THEORY (MCDT) IN VALUE MANAGEMENT

One of the important objectives of developing a decision support system for VM implementation is to formulate a systematic methodology so as to make it, a more scientific and rational

approach for any value enhancement project. Now, the step-by-step procedure of application of multi criteria decision theory in VM implementation through its Job Plan has been described in subsequent paragraphs.

In **information phase** a thorough understanding of the system, operation, or item under study is achieved by a rigorous review of all the pertinent factual data. In **functional phase**, various functions of the system are identified. To identify and classify the basic and secondary functions, eigenvector approach of decision matrix analysis (Kulshrestha, 1996) is carried out. The suggested eigenvector approach is basically a multiplicative approach, whereas the conventional numerical evaluation method of classical VM is an additive approach. In fact, the former approach is mathematically more sound than the latter for the effective analysis of functions.

The eigenvector technique of functional evaluation is accomplished with the preparation of a list of functions in descending order of their importance. Since value management is originally a function oriented approach, the basic function(s) and some important secondary function(s) are identified through the technique and transformed into functional attributes (criteria) for further study. Thus, through the application of decision matrix analysis technique, the basic framework of VM being function centred technique is not affected. Finally, from the ranking list of functions, the first three functions, i.e. one basic and two secondary functions (B, S₁, S₂) are taken as functional attributes along with cost and other attributes for the development of decision support models. Thus, various attributes (criteria) of the MCDT problem are replaced by the following three attributes when it is applied to VM :

- (a) Functional attributes,
- (b) Cost Factor attributes, and
- (c) Other attributes.

As mentioned earlier, the basic underlying principle behind the application of MCDT techniques in VM implementation is the analogy visualized between the two. Accordingly, for illustration purposes, a comparison of decision environments of VM job plan with multi-criteria methodology has been shown in Figure 2.0.

In **creativity phase**, a brainstorming session is conducted by the task group members to explore the possible value alternatives to enhance the value of the system under consideration. All the possible alternatives are listed. This list consists of some infeasible and unmeaningful alternatives too. In **analytical phase**, all the listed alternatives proposals are analysed through preliminary inspection and all the infeasible alternatives are eliminated. In **evaluation phase**, mathematical modelling is carried out to identify the best value alternative. In this phase, for developing the models, various techniques of MCDT are used. Most of the approaches in MCDT consist of the following two stages :

- (a) The aggregation of judgements of the decision makers with respect to all criteria and as per value alternatives, and
- (b) The rank ordering of value alternatives according to the aggregated judgements of the decision makers.

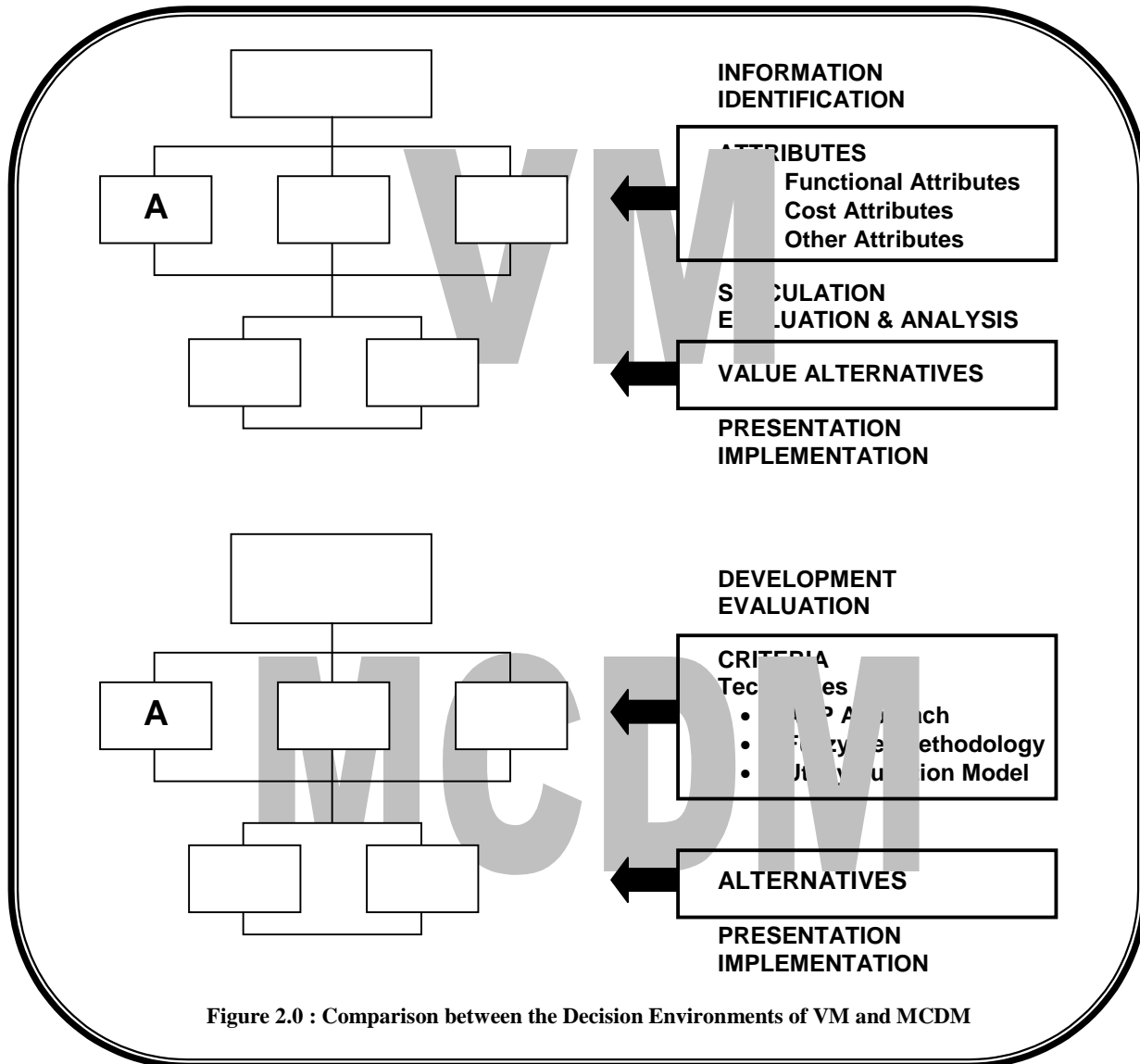


Figure 2.0 : Comparison between the Decision Environments of VM and MCDM

There are a number of techniques available for multi-criteria analysis. Some of the important techniques are as follows :

- (a) Weights and Score Methods,
- (b) Graphical Method,
- (c) Utility Functions Model,
- (d) Multicriterion Q-Analysis II
- (e) Fuzzy Set Methodology, and
- (f) Analytic Hierarchy Process Approach.

Among the above-mentioned list of techniques, the most suitable methods for developing the decision-making models for VM implementation are Analytic Hierarchy Process (AHP)

approach and Fuzzy Set Methodology (FSM). In this paper, these two techniques have been discussed in order to develop the models.

In **recommendation phase**, the top ranked alternative(s) is selected for recommendation and presentation. The recommended alternative is actually implemented and its merits and demerits are studied before presentation.

ANALYTIC HIERARCHY PROCESS (AHP)

The Analytic Hierarchy Process (AHP), axiomised by Thomas C. Saaty, is one of the mostly used MCDT techniques that can be efficiently employed for the present case of Value Management implementation. Because of its simplicity in understanding and operation, this technique has been extensively applied in different fields for decision-making in construction.

The strength of AHP lies in its ability to structure a complex, multi-person and multi-period problem hierarchically. Pair-wise comparison of the elements, usually attributes and value alternatives, can be established using a scale indicating the strength with which one element dominates another. This scaling process can then be translated into priority weights (scores) for comparison of alternatives in classic AHP methodology and of different ratings in AHP Rating Approach.

AHP CONCEPT AND METHODOLOGY

In AHP, the decision maker (DM) constructs a hierarchy, which relates the relevant issues in the decision problem under an overall goal. The hierarchy serves as a framework for addressing both qualitative and quantitative factors simultaneously. (Saaty, 1982).

In order to establish a preference order for the alternatives, the DM carries out a series of pair-wise comparisons. A ratio scale is used such that for each pair-wise comparison, the DM specifies the relative importance of one factor over the other with respect to the given criterion. The pair-wise comparisons are processed so that each decision alternative is assigned a weight in the range of (0, 1). These weights reflect the alternatives' desirability in view of the DM's preferences.

In problem structuring, the relevant criteria in the decision problem are organized into a hierarchy. The topmost element of the hierarchy stands for the overall goal in the decision problem. The level immediately below it consists of sub-goals, which contribute to the attainment of the overall goal. Each sub-goal is decomposed further until a sufficiently detailed representation of the decision problem is obtained. The decision alternatives are put on the lowest level of the hierarchy in classical AHP hierarchy whereas in AHP rating approach, the ratings occupy the lowest level of the hierarchy.

While using this approach in present case, firstly, the priority weights for functional, cost factor, and other attributes as well as their sub-attributes are calculated by the eigenvector method of pair-wise comparison. Finally, global priorities (GP) of various attributes rating are found out. With the help of GP of ratings, all the available value alternatives are evaluated and ranked.

AHP APPLIED TO VM IMPLEMENTATION

The use of AHP technique in terms of step-by-step procedure for its application in VM implementation has been illustrated with the help of a case example in subsequent paragraphs.

For a multi-storeyed office building construction project, VM study is to be carried out for the selection of suitable structural system for the building. The study is accomplished through the job plan. In information phase, relevant information was collected and suitably analysed. Various functions of a structural system were identified and evaluated in functional phase. In creative and analytical phase, a rigorous brainstorming session was conducted for generating some feasible and meaningful value alternatives. At the end of the session, VM team members came up with the following value alternatives :

- (a) Beam and slab system with one secondary beam,
- (b) Beam and slab system with two secondary beams,
- (c) Waffle wall system, and
- (d) Flat slab system.

In considering the above value alternatives, the main criteria kept in view were economy, functional suitability, structural efficiency, partition wall location, and aesthetic aspects etc.

In evaluation phase, AHP technique is applied to develop a model for evaluating various value alternatives. In the model, the evaluation attributes considered are as follows :

- (a) Functional attributes (F Attributes)
 - Transmit load (TL)
 - Distribute force (DF)
 - Assure reliability (AR)
- (b) Cost factor attributes (CF Attributes)
 - Capital cost (CC)
 - Repair and maintenance (RM)
- (c) Other attributes (O Attributes)
 - Structural requirements (SR)
 - Architectural considerations (AC)
 - Space utilisation (SU)

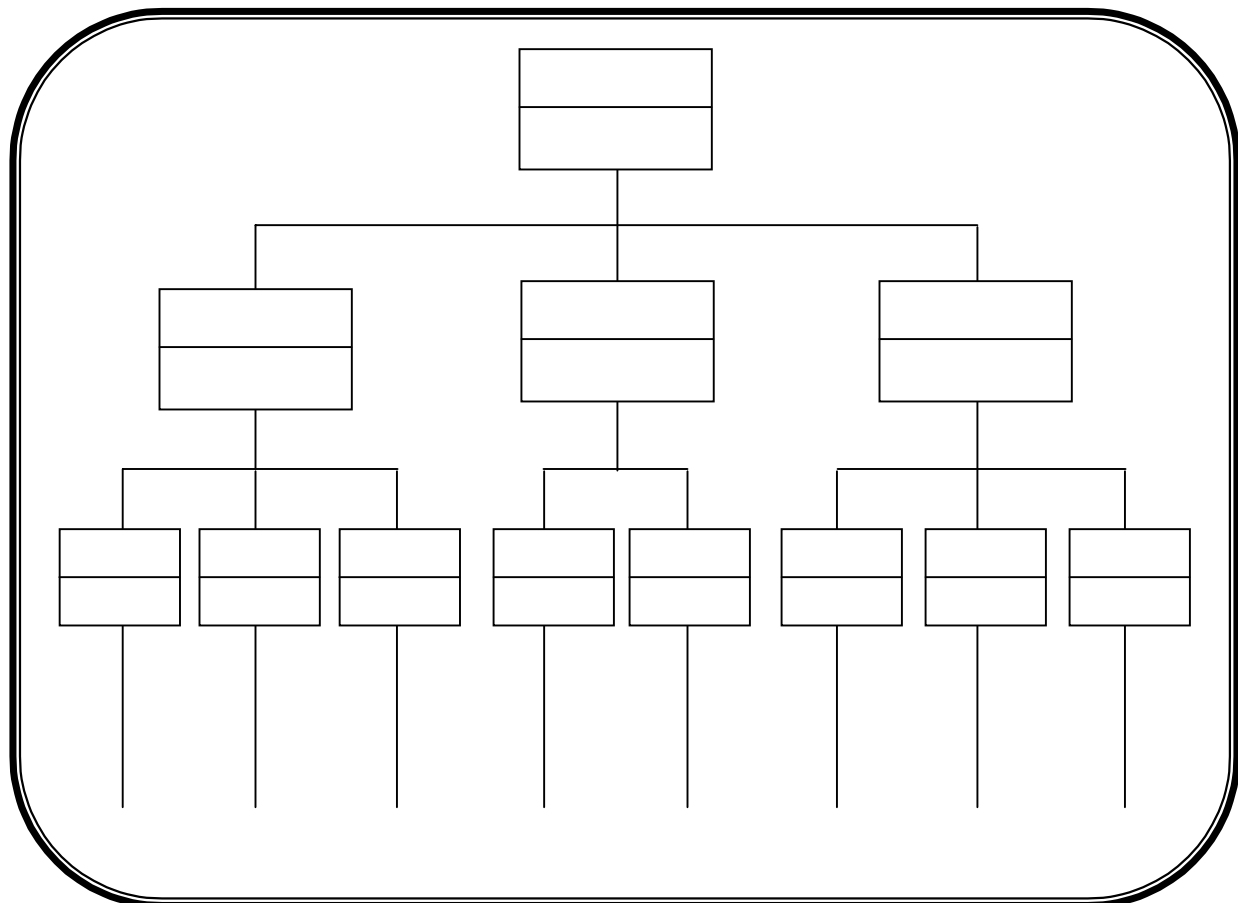
To measure the preference of the value alternatives with respect to “functional attributes” and “other attributes”, the ratings used are : outstanding (O), good (G), satisfactory (S), and poor (P). In case of “cost factor attributes”, the ratings used are high (H), average (A), and low (L).

Finally, in order to select the best value alternative among the different VM proposals, the AHP technique is essentially applied in the following steps :

- (a) Decompose the decision problem
- (b) Establish priorities
 - Construction of square decision matrix
 - Analysis of consistency in decision making
 - Computation of Priority Vector (PV)
- (c) Synthesise
- (d) Determine overall priorities of structural systems

Decompose the Decision Problem

The first step is to decompose the problem into its components and then use these components to develop a hierarchy with a number of levels, namely goal, attributes, sub-attributes, and value alternatives. Here, in this case example, AHP rating approach has been used which is capable of taking care of large number of alternatives. This approach involves determining ratings of achievement or preference for each attribute, and sub-attribute. Accordingly, these ratings have been inserted in place of alternatives in the hierarchical structure shown in Figure 3.0.



Establish Priorities

After arranging the problem in a hierarchical form, the next step is to evaluate each element of the problem. Each node is evaluated against each of its peer with respect to its parent node. These evaluations are called “pair-wise comparisons”. For each level, preferences are made and entered in a square decision matrix and thereafter, matrix is analysed to obtain the Priority Vector (PV) for the particular level of attributes or sub-attributes.

Construction of Square Decision Matrix

In AHP approach, a number of decision matrices are formed to determine the relative weightages of a set of attributes/sub-attributes with respect to their parent nodes with the help of pair-wise comparisons. The pair-wise comparison procedure is started by relating attributes, say, A on the left to the attribute say, B on the top of the matrix and determining which is more important. If attribute A seems to be more important than B, then a suitable integer value from the Table 1.0 is entered in the box of attributes evaluation matrix. If attribute A appears to be less important than B, then the reciprocal of previous integer value is used to make the entry.

Table 1.0 : Scale of Relative Importance in AHP Approach

Intensity of relative importance(s)	Definition	Explanation
1	Equally important attributes	Two attributes contribute equally to the value
3	Moderate importance of one attribute over another	Experience & judgement slightly favours one attribute over other
5	Essential or strong importance	Experience & judgement strongly favours one attribute over other
7	Demonstrated importance	A attribute is strongly favoured & its dominance is demonstrated in practice
9	Extreme importance	The evidence favouring one attribute 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 an attribute is given one of the above numbers when compared with a second attribute, then the second attribute is assigned the reciprocal value when compared with the first attribute.	

Thus, in this technique, two entries are made simultaneously with one judgement, i.e. one integer and its reciprocal at mutually transposed positions. When an attribute 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 $\frac{n(n-1)}{2}$ judgements have to be taken to complete the decision matrix where n is the number of attributes to be analysed at once. This procedure is repeated by comparing one attribute on the left at a time, with all the remaining attributes on the top of the matrix.

For example, Figure 4.0 shows a matrix of judgements resulting from comparing the preference of the sub-attribute (level 3) with respect to the functional attribute. With the hierarchy used here for our case example, 12 such matrices of judgements have been formed.

	A	B	C	D	E	F	G	H	Eigenvector Component of Rows	Priority Vector
A	1	4	5						2.714	0.674
B	1/4	1	3						0.908	0.225
C	1/5	1/3	1						0.405	0.101
D				1						
E					1					
F						1				
G							1			
H								1		
TOTAL									4.027	1.00

Figure 4.0 : Decision Matrix

After constructing the decision matrix, the square matrix gives a way to determine qualitatively the relative importance of the attributes/sub-attributes in a problem situation. The computation of eigenvalues and eigenvectors associated with square decision matrix helps in ranking the attributes according to their relative importance. The eigenvector of the greatest non-zero eigenvalue provides an estimate for the assumed underlying ratio scale.

Analysis of Consistency in Decision Making

Mathematically, the greatest non-zero eigenvalue, (λ_{\max}) should be equal to the order of the decision matrix (n) only when the decision maker (DM) is perfectly consistent in his judgements. On the other hand, in real life, perfect consistency is hard to live up to. However,

to some extent, certain amount of inconsistency of the DM may be accommodated without affecting the overall results.

The deviation of the λ_{\max} from n is regarded as the measure of inconsistency in judgements. In case of slight inconsistency, λ_{\max} will slightly deviate from n on the higher side. Therefore, the closer λ_{\max} is to the order n , the greater is the consistency exhibited by the DM. In order to measure the relative consistency, a Consistency Index (CI) for single matrix is introduced as,

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

A Random Index (RI) is defined as a consistency index of a randomly generated reciprocal matrix. For different order matrices, the corresponding random consistency can be pre-determined. Finally, a Consistency Ratio (CR) is defined as,

The value of Consistency Ratio should be within 10% for good results, but generally, for Value Management implementation purposes, the limit up to 15% may be accepted. In case the CR is higher than the limit, then decision makers (VM team members) should consider for revising their judgements.

Computation of Priority Vector (PV)

Having formed the comparison matrices, the relative weights (priority vectors) of the various elements of the model are determined using eigenvectors. In terms of matrix algebra, the decision matrix analysis consists of determining the PV (eigenvector) of the matrix and then normalising it to 1.0 or 100% to obtain the priority vector, which in fact, can be termed as local priority of the factors considered.

As shown in Figure 3.0, each element has two priorities : the local priority (LP) and the global priority (GP). The LP of an element is the relative priority of the element with respect to its peers. The GP is computed by multiplying the LP of the element by the GP of its parent element. For example, the LP of “transfer load” is 0.674, the global priority of functional attributes is 0.250, therefore the GP of “transfer load” is (0.674×0.250) or 0.168.

Manual computation of the eigenvector 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 techniques, which are good to provide sufficiently close results for the application. Geometric mean approximation, a sound approach to compute PV, is suggested to be used for the present situation.

Synthesise

The global (composite) priorities of the rating (the lowest level of AHP model in Figure 3.0) are determined by aggregating the weights through the hierarchy. The outcome of this process is the ratio scale priorities of the various ratings. For example, the GP of “outstanding” with respect to “transfer load” with respect to “functional attributes” with respect to “goal” is $(0.487 \times 0.674 \times 0.250 \times 1.00)$ or 0.082.

Determination of Overall Priorities of Structural Systems (Value Alternatives)

In this step, a rating spreadsheet (Table 2.0) is used to capture the preference of VM team members for each of the four types of structural systems under consideration. The ratings suggested earlier are used to evaluate each structural system’s achievement against each criterion. For example, in Table 2.0, waffle slab system has been rated high (H) with respect to capital cost. This rating is translated into a priority factor, i.e. GP, which has been determined in the previous step of the process.

Table 2.0 : Structural System Rating Spread Sheet

Evaluation Factor	Structural Systems			
	One Beam	Two Beam	Waffle Slab	Flat Slab
Transmit Load	G	O	G	G
Distribute Force	S	O	G	S
Assure Reliability	G	O	G	G
Structural Requirements	G	O	P	S
Architectural Consideration	S	O	S	G
Space Requirement	O	G	S	O
Sub Total (1)	0.1325	0.1900	0.1115	0.1240
Capital Cost	L	L	H	A
Repair & Maintenance Cost	A	H	H	A
Sub Total (2)	0.3440	0.3250	0.0590	0.1700
TOTAL	0.4765	0.5150	0.1705	0.2940
Percentage of Maximum	92.520	100.00	33.10	57.08

A total priority for each structural system can be computed by summing up the priorities of the ratings of the structural system on each criterion. The value alternative with highest total priority is recommended as it best satisfies the combination of all the three criteria (attributes). In Table 2.0, “percentage of maximum” for a structural system represents the ratio between the priority of the structural system and the highest priority among all structural systems.

Results and Discussion on AHP

The computational results of the case example show clearly the importance of incorporating the attributes for the accomplishment of any VM study. As shown in Table 2.0, if cost factor attributes only are to be considered, the “beam and slab system with one secondary beam” should be selected. On the other hand, if all the attributes are to be considered together, then the “beam and slab system with two secondary beams” should be recommended. In this approach, economical feasibility of various alternatives is taken care of automatically as cost has also been considered as an attribute. As shown in Table 2.0, the “slab system with one secondary beam” is less costly than the “beam and slab system with two secondary beams” but the latter system is preferred from architectural considerations. Thus, the approach provides flexibility in selecting and recommending the appropriate value alternative with respect to a set of given attributes/sub-attributes.

FUZZY SET METHODOLOGY (FSM)

The Fuzzy Set Methodology, axiomised by L. A. Zadeh, is a powerful qualitative technique for analyzing the decision problem involving ‘fuzzy’ information. Since many of the real life information are fuzzy in nature, this method has been most widely adopted in almost all fields of decision-making. Particularly, in construction, the projects nowadays are quite complex, each with hundreds of operations and activities, and containing most of the information in fuzzy form. Construction engineers use different skills and strategies of varying degree of complexity for accomplishing the tasks.

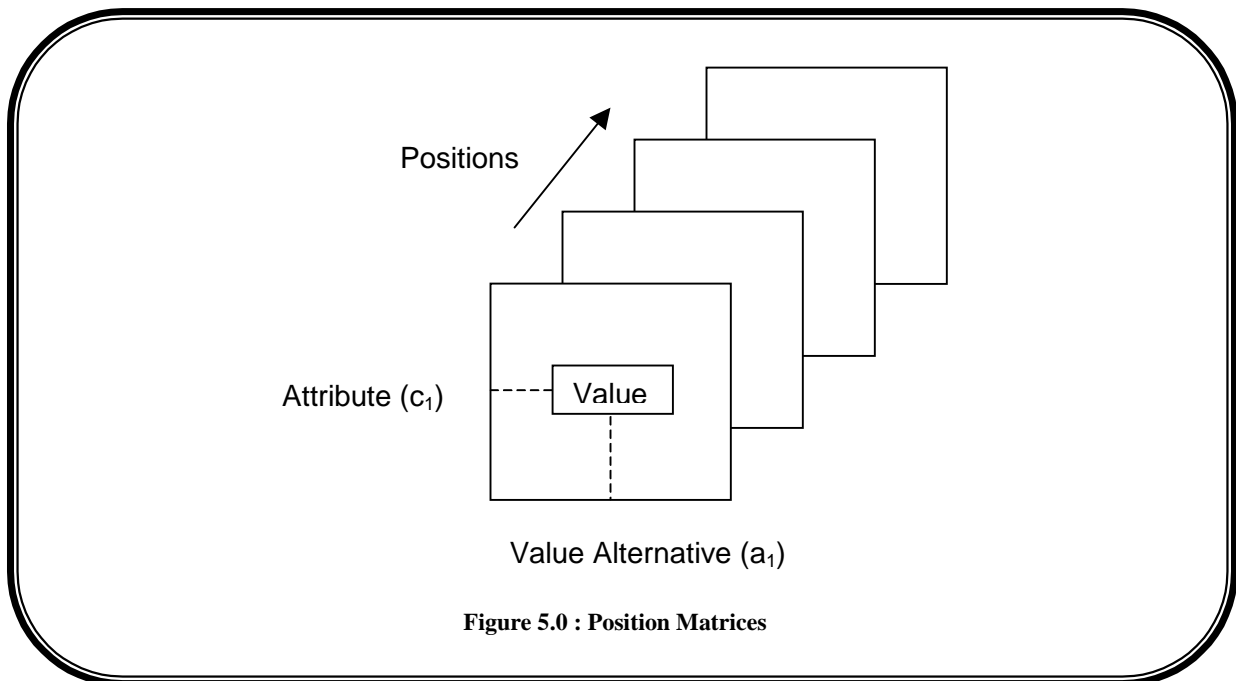
Fuzzy set methodology is one such technique, which is capable of incorporating the imprecise and vague but quite significant qualitative data together with the well defined quantitative information into the decision-making process. The concept of fuzzy set is founded on the notion that qualitative expressions usually involve the realm of human perception, subject to a range of interpretations. The qualitative expressions usually consist of linguistic variables and linguistic values.

In this paper, the dominance matrix approach of Fuzzy Set Methodology (FSM) has been discussed for multi-criteria evaluation of value alternative proposals emerged during creative and analytical phases in an integrated manner with eigenvector approach being used for weight assessment of the attributes.

FSM APPLIED TO VM IMPLEMENTATION

In VM, the fuzzy theoretic methodology for multiple criteria decision making is characterised by a set of value alternatives, a set of evaluation attributes and a VM team of number of decision makers, each with his own set of viewpoints. The fuzzy set methodology is designed such that quantitative and non-quantitative attributes and the view points of the VM team members can be readily incorporated into the decision making process. Ranks of the value alternatives in a group decision process are achieved through a dominance matrix designed for the purpose.

In evaluating any finite set of n value alternatives, $A (a_1, a_2, a_3, \dots, a_n)$ across a set of m attributes, $C (c_1, c_2, c_3, \dots, c_m)$, one can assign a value for each attribute and for each value alternative. In order to represent the views of each of the member of VM team, a position matrix is prepared from the response of VM team members by giving the numerical values to the qualitative assessment. As shown in Figure 5.0, a set of position matrices with value alternatives on one axis and the attributes on the other can be constructed. A cell in a matrix represents the membership value of an attribute for a value alternative. Since one position matrix would not adequately define the positions of all VM team members, a series of matrices can be developed over a range of position. Since the evaluation is based on subjective interpretations, there is no choice but to tolerate some level of imprecision and ambiguity.



The concept of membership plays a central role in this application. Membership is defined over a range from 0 (low) to 1 (high) against some qualitative scale. By convention, low represents the least desirable end of the scale and the high represents the most desirable end of the scale. The membership value of 1.0 is treated as complete satisfaction of needs associated with the qualitative attribute and the membership value of 0.0 is complete dissatisfaction.

In function phase, weightage of each function is worked out using eigenvector approach and are ranked in order to identify the basic and secondary functions. These functions play vital role in selecting the value alternatives during creative and analytical phases.

In evaluation phase, first of all, the weightage of each functional attribute is worked out using the eigenvector approach indicated for each position matrix of the respective VM team member. By raising the membership values of the position matrix to the power of the assigned weight, some of the biases in the matrix can be eliminated. With the introduction of weights,

dominances of insignificant features are rightly ignored thereby making the evaluation more precise, realistic and useful. Thus, the weighted matrices for each of the experts are prepared. The weighted position matrices so obtained are aggregated by using the following aggregation procedures :

- (a) Pessimistic Aggregation
- (b) Optimistic Aggregation
- (c) Mean Aggregation
- (d) Modified Pessimistic Aggregation

Optimistic/pessimistic aggregation is done by considering the highest/lowest values of the responses from various VM team members. Mean aggregation is done by computing the average/mean of various responses. Modified pessimistic aggregation is the average of mean and pessimistic aggregation. The most useful aggregation of the various matrices is the modified pessimistic aggregation, which attempts to minimise the risk. Hence, for the present case, modified pessimistic aggregation approach is proposed to be used for aggregating the weighted position matrices obtained on the basis of judgements of various experts.

In order to define a basis on which one value alternative can be considered superior to another, the concept of dominance is evolved. A value alternative is said to dominate another for a given attribute if and only if its aggregate membership value is greater than that of other value alternative. A value alternative is said to be superior to a second alternative if it dominates the second value alternatives in more features than the number of attributes in which the second dominates the first.

In order to display the dominance structure between all the possible pairs of value alternatives, a $(n \times n)$ matrix D called dominance matrix is constructed. The element d_{ij} is the number of attributes for which the membership value of alternative j is greater than that of value alternative i . The dimensionality n is equal to the number of value alternatives under considerations. A dash (-) is entered in the diagonal cells, as the dominance of a value alternative over itself does not make any sense. If the k th column is summed, the total number of dominances of value alternative k over all others alternatives is obtained. Similarly, if the k th row is summed, the number of times the k th alternative is being dominated by all the other alternatives is determined. The sums of columns and rows can be compared. The most favourable value alternative is one which has the highest column sum and lowest row total. This value alternative is selected for recommendation as it satisfies the combination of system requirements in most efficient manner.

In many cases, there may be value alternatives, which are very close on the dominance matrix. In these situations, the magnitude of domination, which is the difference in the membership value in the aggregate matrix, can be examined. Because of the 'uncertainty' or 'fuzziness' of the information contained in the aggregate matrix entries, it is useful to obtain the equivalence limit. That is, if the membership values of two value alternatives are within the specified limit,

these value alternatives can be considered equivalent with respect to that attribute. This range may be set arbitrarily, (for example, 4% of the membership value) but should not be too large, otherwise much information may be lost, consequently affecting the comparison of value alternatives. However, for the present case, a tolerance limit of ± 0.05 is proposed. Thus, a value alternative with membership value of 0.75 in its i th attribute, for example, does not dominate another alternative upto a membership value of 0.70 and in turn, is not dominated by an alternative with its i th attribute membership value upto 0.80.

CONCLUSIONS

The use of Multiple Criteria Decision Theory (MCDT) techniques in Value Management (VM) implementation has been found as a useful tool for considering the multiplicity of attributes arising in multicriteria evaluation.

The AHP technique of MCDT has been found the most suitable approach for VM implementation. It is suitable when the set of attributes can be decomposed hierarchically in terms of goal, attributes and sub-attributes etc. It provides a framework for group participation in decision-making or problem solving as a VM team. This methodology also encompasses the functional approach of VM through the set of functional attributes analysed during the evaluation. The AHP technique is primarily not suitable for large number of decision matrices. To overcome this problem, AHP rating sheet approach as discussed in the paper has been suggested.

In AHP technique, 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 by the VM team members. The concept of consistency determination in AHP also makes the VM more scientific and rational because one may not desire VM to be based on judgements that have such low consistency that they appear to be random. It also gives the decision maker the scope for revising and improving the judgements.

The fuzzy set methodology for the evaluation of value alternatives is suggested to be used when the basic function of the system or component has distinct difference of margin with highest order secondary function. In other words, the model is suitable when the basic function of the system is so distinct that it is not necessary to include it in the set of attributes. The method is capable of handling a fairly large number of value alternatives.

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