PERFORMANCE EVALUATION OF AN IRRIGATION SYSTEM BY ANALYTIC HIERARCHY PROCESS : A CASE STUDY

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ABSTRACT

The selection of the best irrigation system is examined in the multiobjective context for a case study of Sri Ram Sagar Project, Andhra Pradesh, India. Eight performance criteria, on farm development works, environmental impact, supply of inputs, conjunctive use of water resources, productivity, farmers' participation, economic impact and social impact are evaluated for thirteen irrigation systems (D1,D2,…..,D13). Analytic Hierarchy Process (AHP) is employed to overcome the difficulties arising from the complexity, subjectivity and lack of group consensus in the evaluation of an irrigation system. Kendall rank correlation test is employed to assess the correlation between the different groups of ranking pattern. Group consensus is achieved through Geometric ranking rule (multiplicative ranking). It is observed that irrigation systems D8 and D11 occupied first and second positions respectively. Studies revealed that AHP is quite accessible and conductive to group consensus building. Comparison of the results indicated that the methodology is quite versatile and can be used in any field of engineering and management with suitable modifications.

KEYWORDS

Analytic Hierarchy Process, Multicriterion Decision Making, Performance Evaluation, India

INTRODUCTION

Multicriterion Decision Making (MCDM) methods are gaining importance because of their inherent ability to judge different alternative scenarios for possible selection of the best which may be further analyzed in depth for its final implementation. Development of water resources for projects such as irrigation has played an important role in the improvement of socio-economic conditions in developing countries. However, in recent years, there has been a growing disappointment in the levels of productivity, benefits and sustainability of many irrigation schemes. In addition, for the foreseeable future, shrinking budgets for development, operation and management of schemes necessitate improvements in project performance in place of new developments. To cater the situation, performance of irrigation systems (distributories) can be evaluated and strategies can be developed to choose the best one, which in turn can be used for formulating guidelines to improve the performance and efficiency of other existing ones.

In the present study, concept of MCDM is demonstrated with the case study of Sri Ram Sagar Project, Andhra Pradesh, India to find the best performing irrigation system. Analytic Hierarchy Process (AHP, Utility type of MCDM method) is employed to overcome the difficulties arising from the complexity, subjectivity and lack of group consensus in the evaluation of an irrigation system. Methodology of AHP is briefly discussed below.

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ANALYTIC HIERARCHY PROCESS

Analytic Hierarchy Process is an MCDM technique based on priority theory. It deals with complex problems which involve the consideration of multiple criteria simultaneously. Its ability (1) to incorporate data and judgements of experts into the model in a logical way, (2) to provide a scale for measuring intangibles and method of establishing priorities, (3) to deal with interdependence of elements in a system, (4) to allow revision in a short time, (5) to monitor the consistency in the decision maker 's judgements, (6) to accommodate group judgements if groups can not reach a natural consensus, makes this method a valuable contribution to the field of MCDM (Saaty & Ghoolamnezhad 1982). It is capable of a) breaking down a complex, unstructured situation into its component parts, b) arranging these parts or variables into a hierarchic order, c) assigning numerical values 1 to 9 to subjective judgements on the relative importance of each variable and d) synthesizing the judgements to determine the overall priorities of the variables. Eigen vector approach is used to compute the priorities of the elements in each pairwise comparison matrix. Eigen vector corresponding to maximum eigen value (λ_{max}) is then weighted with the weight of higher level element which is used as the criterion in making the pairwise comparisons that constitute the matrix in consideration. The procedure is repeated by moving downward along the hierarchy, computing the weights of each element at every level, and using these to determine composite weights for the succeeding levels. Since small changes in elements of pairwise comparison matrix imply a small change in λ_{max}, the deviation of the latter from matrix size N is a deviation of consistency. This is represented by $(\lambda_{max} - N) / (N-1)$ and termed as Consistency Index (CI). When the consistency has been calculated, the result is compared to those of the same index of a randomly generated reciprocal matrix from the scale 1 to 9, with reciprocals forced. This index is termed as Random Index (RI). The ratio of CI to average RI for the same order matrix is called the Consistency Ratio (CR). A CR of 0.1 or less is considered acceptable. The reciprocal property is preserved in these matrices to improve consistency. If consistency ratio is significantly small the estimates are accepted. Otherwise, an attempt is made to improve consistency by obtaining additional information.

RESULTS AND DISCUSSION

The above methodology is applied to the case study of thirteen irrigation systems of Sri Ram Sagar Project, Andhra Pradesh, India. Eight different performance criteria, on farm development works, environmental impact, supply of inputs, conjunctive use of water resources, productivity, farmers' participation, economic impact, and social impact are evaluated for selecting the best irrigation system. These are denoted as OFD, EIM, SOI, CWU, PRO, FAP, ECI, and SCI respectively. All the criteria are assumed to be qualitative due to lack of precise quantitative information. A three stage procedure is employed to select the best irrigation system. In the first stage weightage of the performance criteria is obtained. In the second stage, group decision making concept is incorporated. In the third stage, global priority of each irrigation system is obtained.

Stage 1 : weightage of performance criteria (level 2 to level 1)

Irrigation management expert is chosen for the decision making process because of his extensive knowledge about the irrigation systems. Fig. 1 presents listing of the attributes and structure of the hierarchy. Level 1 corresponds to the objective of the good irrigation system, level 2 corresponds to the performance criteria and level 3 corresponds to the alternatives (irrigation systems). Total

347 individuals (329 farmers and 18 authorities) belonging to thirteen irrigation systems are interviewed. These irrigation systems are termed as D1, D2, D3, D4 ....and D13 for academic purpose. Analytic Hierarchy Process is employed to obtain the weightage of each performance criteria. Both farmers and authorities are introduced to Saaty's 1-9 ratio scale with examples and requested to express their preferences for each of the eight performance criteria at the second level with respect to the overall goal of selecting good irrigation system (level 1). This requires 28 pairwise comparisons on Saaty's scale. This is based on the size of the pairwise comparison matrix N x N i.e., N(N-1)/2 where N=8. Among 64 elements/responses (8 x 8 matrix), eight diagonal elements are of value 1. Among the other available 56 elements, the value of the 28 elements are simply reciprocal of other 28 based on reciprocal theorem (Saaty 1992). In the questionnaire, questions are asked about only 28 elements of upper triangular matrix corresponding to pairwise comparison matrix. Eigen vector approach is employed to find the weightage of the criteria, consistency index and the consistency ratio corresponding to maximum eigen value (Saaty & Ghoolamnezhad 1982). Users can modify their views in pairwise comparison matrix until judgements (consistency ratio) are satisfactory. Pairwise comparison matrices corresponding to all the 347 individuals are recorded and weightage of the performance criteria is obtained by the above procedure. It is observed that (results are not presented due to space limitation) judgements are satisfactory i.e., consistency ratio is less than or approximately equal to 0.1. Economic impact is given first position by 76.5% farmers in irrigation system D1, 40.0% farmers in D3, 57.7% farmers in D4, 72.4% farmers in D5, 88.9% farmers in D6. In these irrigation systems individuals felt the need of social upliftment and more agricultural productivity. In the remaining irrigation systems economic impact is given first position by all respondents. Second position is occupied either by social impact or productivity.

Stage 2 : group decision making

It became difficult to arrive at a group consensus on the priority of the performance criteria obtained from stage 1 of the analysis. This is due to lack of interaction between farmers (since most of the interviews are held separately) and individuals inability to arrive at a natural consensus even among the available ones. To overcome this drawback, a pairwise comparison matrix of each individual (irrigation system wise) is aggregated to arrive at a group pairwise (irrigation system wise) comparison matrix by geometric mean approach. Irrigation system wise aggregation is chosen due to the computational difficulties in aggregating all the 347 individual pairwise comparison matrices at a time. Table 1 presents the irrigation system wise weightages of the performance criteria and consistency ratio with respect to the overall goal of selecting good irrigation system. It is observed that economic impact, social impact and productivity occupied first, second and third positions respectively. Consistency ratio varies from 0.01109 to 0.05365 indicating the satisfactum of judgements. Later, these 14 sets of weightages (13 irrigation systems and one authority related) are geometrically aggregated (Saaty 1992) to obtain the average weightage of performance criteria corresponding to all 347 individuals and presented in Table 1. The priorities of the criteria in the decreasing order are economic impact (0.309), social impact (0.223), productivity (0.148), environmental impact (0.081), conjunctive use of water resources (0.062), on farm development works (0.061), farmers participation (0.057) and supply of inputs (0.052). These weightages are used for calculating the global priorities of irrigation systems which are discussed in the next section. However, 14 sets of weightages are subsequently used for the sensitivity analysis studies. Notations in Table 1 are as follows: Rows D1 to D13 represent irrigation systems, row 14 represents priorities of authorities, row 15 represents geometrical average of 347 individuals, NP represents number of individuals and CONRA represents Consistency ratio.

Stage 3 : priority of irrigation systems (level 3 to level 2)

Preferences of thirteen irrigation systems at the third level with respect to each performance criteria at the second level require 78 pairwise comparisons. It is observed that (results are not presented due to space limitation) irrigation systems D1, D2, D3 and D4 are given 2 times importance as compared to D5 for on farm development works. In case of environmental impact , D5 is given 2 times importance as compared to D1, D2, D3 and D4. Similarly, pairwise comparisons of D8 with other irrigation systems are also differed both for environmental impact and on farm development works. Similar pairwise comparisons are observed when comparing D10, D11 and D13 with other irrigation systems. For supply of inputs, irrigation systems D1, D2 and D3 are given 1, 2 and 2 times importance as compared to D6 and 2, 3, 3 times in case of conjunctive use of water resources. Similarly D8 is given 3 times importance as compared to D1 for supply of inputs, 4 times for conjunctive use of water resources. In case of productivity , D1 and D2 are given 3 times importance as compared to D5. In case of farmers' participation, D5 is given 3 times importance as compared to D1 and D2. Similarly D8 is given 3 times importance as compared to D1 for productivity and it is 7 times in case of farmers' participation. For economic impact, D8 is given 9, 4, 9, 9,4,6, 5 times importance as compared to D1 to D7. In case of social impact, these are 3, 4 , 2, 4, 4, 4, 5 indicating that economic impact is very high in case of D8 when compared to D1, D3 and D4. Farmers' participation achieved a high consistency ratio of 0.1002 which is slightly beyond the normal value of 0.1. For on farm development works, environmental impact , supply of inputs and social impact these values are in the range of 0.0922 to 0.0953. In case of economic impact criterion, consistency ratio is less (0.0726) compared to all other criteria. Above pairwise comparisons are based on the available data with expert and his ability to correlate the real (irrigation system) situation. Table 2 shows the global priorities and the ranking of each irrigation system. The summation of the products of the local priorities of irrigation systems by the higher level average local priorities of performance criteria (corresponds to geometric mean) yields the global priority of each irrigation system. It is observed that irrigation systems D8 and D11 occupied first and second positions respectively with a priority value 0.2352 and 0.1706 respectively. Least positions are occupied by irrigation systems D12, D13 with priority values of 0.0414 and 0.0388 respectively.

Sensitivity analysis is performed in three phases to assess the robustness in ranking pattern. In phase 1 of the analysis, fourteen sets of local priorities of performance criteria (13 irrigation systems and one authority related;Table 1) are used. Ranking pattern is same as those obtained from the geometric mean approach (Table 2). In the second phase, value of each weight of the criteria is increased and then decreased as much as possible without changing the order of the criteria. Social impact is the second largest criterion occupying a weightage of 0.223. The adjacent values are 0.309 (economic impact) and 0.148 (productivity). Therefore two sensitivity runs are performed for this criterion to investigate the influence of values upto 0.308 and 0.149 on the ranking respectively. This represents the range that maintains the same order. Similar analysis is also done for other criteria. Table 3 shows the ranges of weightages of criteria employed. Total 14 combinations of weightage are evaluated. It is observed that all the 14 combinations have fallen into four groups (S1 to S4) of ranking pattern as shown in Table 4. In phase 3 study is made with equal weightage of the criteria and corresponding ranking pattern (S5) is also presented in Table 4. Sensitivity analysis studies indicated that the rankings of the irrigation systems remained essentially the same as far as the first, second and third positions are concerned.

Table 1 Priority of performance criteria

Dist	NP	OFD	EIM	SOI	CWU	PRO	FAP	ECI	SCI	CONRA
D1	23	.057	.073	.052	.066	.175	.069	.285	.223	.01323
D2	17	.054	.076	.046	.065	.155	.058	.318	.228	.01635
D3	25	.065	.082	.058	.074	.174	.066	.250	.232	.01296
D4	26	.057	.078	.053	.070	.148	.070	.282	.244	.01109
D5	29	.059	.079	.050	.065	.148	.061	.310	.228	.02503
D6	18	.058	.072	.042	.054	.117	.053	.364	.240	.02387
D7	33	.061	.081	.049	.063	.136	.056	.350	.205	.02334
D8	38	.060	.080	.049	.061	.122	.053	.371	.203	.03258
D9	27	.058	.086	.053	.060	.133	.048	.346	.215	.03587
D10	33	.064	.081	. 053	.058	.134	.050	.354	.206	.03781
D11	21	.063	.087	.053	.053	.145	.052	.328	.219	.04405
D12	19	.066	.087	.056	.060	.148	.057	.303	.222	.04840
D13	20	.067	.093	.056	.059	.163	.055	.288	.219	.05365
14	18	.067	.084	.058	.061	.198	.059	.222	.251	.02930
15	347	.061	.081	052	.062	.148	.057	.309	.223	

Table 2 Global priorities of irrigation systems

Dist	OFD	EIM	SOI	CWU	PRO	FAP	ECI	SCI	Global Priority	Rank
	0.061	0.081	0.052	0.062	0.148	0.057	0.309	0.223		
D1	0.063	0.054	0.064	0.081	0.091	0.083	0.070	0.074	0.0729	3
D2	0.052	0.042	0.066	0.073	0.084	0.055	0.048	0.051	0.0563	7
D3	0.083	0.078	0.063	0.071	0.071	0.063	0.055	0.059	0.0633	5
D4	0.038	0.041	0.043	0.045	0.050	0.048	0.042	0.045	0.0438	10
D5	0.055	0.083	0.069	0.075	0.075	0.077	0.047	0.048	0.0590	6
D6	0.063	0.060	0.051	0.051	0.060	0.059	0.043	0.046	0.0503	9
D7	0.045	0.050	0.045	0.044	0.052	0.049	0.076	0.080	0.0637	4
D8	0.270	0.213	0.251	0.219	0.183	0.203	0.317	0.171	0.2352	1
D9	0.039	0.045	0.041	0.046	0.050	0.045	0.058	0.065	0.0534	8
D10	0.041	0.046	0.043	0.046	0.045	0.046	0.041	0.047	0.0437	11
D11	0.163	0.201	0.170	0.154	0.162	0.184	0.132	0.227	0.1706	2
D12	0.044	0.044	0.053	0.049	0.041	0.050	0.035	0.043	0.0414	12
D13	0.043	0.041	0.041	0.045	0.036	0.038	0.036	0.042	0.0388	13

Table 3 Weightage of criteria and its ranges

Criteria	Weightage	Minimum	Maximum
ECI	0.309	0.309	------
SCI	0.223	0.149	0.308
PRO	0.148	0.082	0.222
EIM	0.081	0.063	0.147
CWU	0.062	0.061	0.080
OFD	0.061	0.058	0.061
FAP	0.057	0.053	0.060
SOI	0.052	-------	0.052

Table 4 Ranking of irrigation systems

Dist	S1	S2	S3	S4	S5
D1	3	3	3	3	3
D2	7	7	7	7	6
D3	5	5	4	4	4
D4	10	11	10	11	12
D5	6	6	6	6	5
D6	9	9	9	9	8
D7	4	4	5	5	7
D8	1	1	1	1	1
D9	8	8	8	8	9
D10	11	10	11	10	11
D11	2	2	2	2	2
D12	12	12	12	12	10
D13	13	13	13	13	13

Table 5 Kendall rank correlation coefficient values

	S1	S2	S3	S4	S5
S1	1.0000	0.9744	0.9744	0.9487	0.8205
S2		1.0000	0.9487	0.9744	0.8462
S3			1.0000	0.9744	0.8462
S4				1.0000	0.8718
S5					1.0000

Kendall rank correlation coefficient is used to determine the correlation between ranks obtained by sensitivity analysis scenarios. In this method, the first step is to arrange the (X,Y) pairs so that X values (ranks) appear in increasing order of magnitude. In this arrangement, if U is the number of pairs of Y values (ranks) that appear in natural order then Kendall rank correlation coefficient (T) is defined as [(4U/D)-1], where D=n(n-1) and n =number of alternatives. The value of Kendall rank correlation coefficient is always between –1 to +1. If T=1 then it is perfect agreement and T= -1 it is perfect disagreement. In the present study Kendall rank correlation coefficient is computed to assess the degree of correlation between five groups S1 to S5 (four from phase 2 and one from phase 3) of ranking pattern. In the five groups, each group is correlated to the other four groups resulting in 20 such combinations. Since correlation between any two, say A and B, is same as that between B and A, out of 20, only 10 combinations are needed to be evaluated. Table 5 shows the coefficient values between groups corresponding to Table 4. Degree of correlation ranges from 0.8205 to 0.9744 indicating the good measure of association between different groups of ranking pattern (Srinivasa Raju, 1995).

In the present study irrigation system D8 is found to be the best followed by D11 which may be further analyzed in depth for final implementation. The ranks may, however, change depending on not only the different criteria and relative importance chosen but also the precision of the available data. Presently studies are in progress for considering more number of irrigation systems in the multiple decision maker environment.

CONCLUSIONS

Analytical Hierarchy Process is employed in performance evaluation studies to a case study of Sri Ram Sagar Irrigation Project, Andhra Pradesh, India. From the analysis of results the following conclusions are drawn:

- It is observed that economic impact is given higher importance followed by social impact/ productivity by most of the individuals.
- Irrigation systems D8 and D11 occupied the first and second positions respectively.
- Analytic Hierarchy Process is found to be suitable for complex group decision making situations where subjectivity plays a major role.
- Kendall rank correlation coefficient is found to be useful to assess the correlation between the different groups of ranking pattern.

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