Raju, K. Srinivasa; Kumar, D. Nagesh

Selection of Suitable Irrigation Planning Strategy Using S/N Ratio and Topsis

Proceedings of ninth International Conference on Hydro-Science and Engineering (ICHE 2010), IIT Madras, Chennai, India.
2 - 5 August 2010

SELECTION OF SUITABLE IRRIGATION PLANNING STRATEGY USING S/N RATIO AND TOPSIS

K. Srinivasa Raju[1] and D. Nagesh Kumar[2]

Abstract: *The present paper deals with selection of a suitable strategy for irrigation planning using Signal to Noise (S/N) ratio method and Multicriterion Decision Making method, namely, Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) for a case study of Sri Ram Sagar Project, Andhra Pradesh, India. Three objectives, net benefits, agricultural production and labour employment are considered. Optimisation, clustering and selection are performed to arrive at the best strategy. Two methods are yielding the same two strategies as the potential ones for further analysis. Kendall rank correlation test is used to assess the correlation between the ranking patterns obtained by two methods. It is observed that the ranking pattern is less sensitive to the chosen parameters of TOPSIS whereas S/N ratio is robust.*

Keywords: *Irrigation planning; Multicriterion decision making; S/N ratio; TOPSIS*

INTRODUCTION

Most of the irrigation systems in developing countries require improvements to increase their level of agricultural production thus providing employment to rural labour such thatthe resulting benefits will be significant. This requires development of irrigation planning strategies in the multiobjective framework so that a suitable strategy can be selected from those developed that can be used as the basis for further improvement of the system. In other perspective, Multicriterion Decision Making (MCDM) methods are becoming important due to their flexibility to analyze alternative strategies in a sustainable way for selection of the suitable one (Raju and Nagesh Kumar, 2010). The versatility of these methods was demonstrated, in solving many concurrent problems in water resources planning (Duckstein et al., 1994, Raju and Nagesh Kumar, 1999). However, most of the MCDM methods, applied to various real world situations in water resources planning, contain some inherent limitations such as (1) requirement of prior information about numerous parameters from the decision maker (2) requirement of extensive sensitivity analysis for arriving at a suitable and robust strategy resulting in computational complexity and burden on the decision maker (3) lack of consideration of uncertainty in inputs resulting in variation in output.

[1] Associate Professor, Civil Engineering Department, Birla Institute of Technology and Science, Pilani- Hyderabad campus 500 078, India; Email: ksraju@bits-hyderabad.ac.in
[2] Professor, Department of Civil Engineering, Indian Institute of Science, Bangalore 560 012, India; Phone : 91-80-2293 2666 (Office); Email: nagesh@civil.iisc.ernet.in

The above limitations necessitated evolving a methodology that can be used as an alternative to

MCDM methods in terms of (1) requirement of less number of parameters (2) non requirement of sensitivity analysis (3) flexibility to consider tolerable variations in input factors that will affect or vary the output. For example, in irrigation planning, two input factors, namely, labour employment and agricultural production affect net benefits. A small deviation/uncertainty in any of the input values or both that may arise due to spatial and temporal fluctuations in different situations such as floods or droughts, market prices of crops, labour and fertilizer availability etc. may change the net benefits. Such variations are quite common in real world problems and have to be considered systematically while selecting the suitable strategy.

In this regard, concept of Signal to Noise (S/N) ratio is used in MCDM framework. Resulting solution from S/N ratio method is compared with that from Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS). This paper is an extension of the study performed by Raju (1995), Raju and Nagesh Kumar (1999) for the case study of Sri Ram Sagar Project (SRSP), Andhra Pradesh, India where selection of the best/suitable irrigation development strategies is examined. Three conflicting objectives, net benefits, agricultural production and labour employment were considered. They proposed a procedure that combines multiobjective optimization, cluster analysis, and MCDM methods. Sensitivity analysis is also performed. The present study deviates from the above studies in (1) introducing simple methodology, namely, S/N ratio as an alternative to existing MCDM methods in which sensitivity analysis of parameters not required (2) comparative analysis of S/N ratio with MCDM method, TOPSIS (3) Application of Kendall rank correlation coefficient for assessing the correlation values. Description of the proposed methodology is presented next.

VARIOUS PHASES OF DECISION MAKING

Phase 1: Individual Optimisation

Three objectives, namely, net benefits, agricultural production and labour employment are considered in the present planning problem Weights of the criteria are estimated using Analytic Hierarchy Process (Saaty and Gholamnezhad, 1982) and are found to be 0.5613, 0.3124, and 0.1263 respectively. The model is subjected to several constraints such as continuity equation, crop land requirements, water requirement of crops, ground water withdrawals, water quality, canal capacity, reservoir storage, downstream water requirements etc. Optimisation of each objective is performed with a Linear Programming algorithm that gives the cropping pattern, reservoir scheduling and ground water withdrawal. Upper (U) and lower (L) bounds of the objective function are obtained and used as the basis for multi objective analysis and presented in Table 1. It may be observed from Table 1 that the planning objectives conflict with one another in terms of their outcomes, necessitating a multiobjective irrigation planning model.

Table 1. Salient features of individual optimal plans and suitable/best plans

Criteria	Units	Solution from maximization of			Solution of G4/P23	Solution of G5/P29
		labour employment	Agricultural Production	Net Benefits		
Net benefits	Million Rupees	1 418.60	1 084.00^{L}	1 672.90^{U}	1586.50	1599.40
Crop production	Million Tons	0.55^{L}	0.78^{U}	0.68 0.74119		0.66374
Labour employment	Million Man-Days	46.23^{U}	35.16^{L}	40.43 40.331		43.239

Phase 2: Multiobjective Optimisation
Constraint method of multiobjective optimisation is applied to analyse the problem in multiobjective framework (Raju, 1995). Maximisation of net benefits is selected as the objective function in this method and the other two objectives agricultural production and labour employment are considered as additional constraints in the existing constraint set. Thirty seven nondominated strategies termed as P01 to P37 are developed by varying the values (within bounds) of the agricultural production and labour employment (not presented here due to space limitation). Table 2 presents the weighted normalised strategy values (normalisation is performed by the difference between the maximum and minimum values of each criterion).

Phase 3: Cluster Analysis
It would be felt by decision maker that the 37 developed strategies are considerably large in number and that some of the strategies are similar in their outcomes. In other words there are tolerable variations in some of the strategies and this type of characteristic strategies can be grouped into similar/ homogeneous sets for further analysis. Cluster analysis (Jain and Dubes, 1988) is used for this purpose and the 37 strategies are classified into 6 groups. It may be observed from Table 2 that the number of strategies in the sixgroups is 7, 7,6, 5, 6 & 6resulting in an equitable distribution. With this grouping, it is now computationally flexible for decision maker as decision making becomes less tedious.

Phase 4: Selection of Suitable Strategy
S/N ratio and TOPSIS methods are described briefly including comparative analysis of the ranking pattern.

S/N ratio method transforms the effect of slightly different values of the input factor into a single value of output. The method is based on ratio of mean response (signal) to standard deviation (noise) resulting due to undesirable and uncontrollable sources that cause deviation from target value as explained with reference to irrigation planning. It reflects the amount of variation from the mean response and is considered as the objective function (Ross, 2005). S/N ratio is maximum for a group having the minimum variance of error (Aomar, 2002).

Table 2. Weighted normalised strategies and corresponding square error values

Group No.	Policy No.	Labour employment	Crop Production	Net Benefits	Squared error values
1 P01		0.4010	1.0867	1.0335	0.0043004
P02		0.4012	1.0866	1.0586	0.0016388
P03		0.4014	1.0863	1.0836	0.0002383
	P04*	0.4021 1.0858		1.0981	0.0000014(MIN)
P05		0.4028	1.0850	1.1177	0.0003493
P06		0.4041	1.0841	1.1416	0.0018177
P07		0.4049	1.0834	1.1593	0.0036450
2 P08		0.4067	1.0825	1.1808	0.0037089
P09		0.4086	1.0816	1.2022	0.0015537
P10		0.4105	1.0807	1.2235	0.0003293
P11*		0.4141	1.0792	1.2409	0.0000009(MIN)
P12		0.4174	1.0773	1.2605	0.0003902
P13		0.4208	1.0753	1.2801	0.0015795
P14		0.4275	1.0745	1.3020	0.0039036
3 P15		0.4309	1.0716	1.3267	0.0030889
P16		0.4343	1.0688	1.3514	0.0009371
P17*		0.4391	1.0672	1.3722	0.0000863(MIN)
P18		0.4439	1.0656	1.3919	0.0001247
P19		0.4497	1.0648	1.4122	0.0010398
P20		0.4555	1.0640	1.4324	0.0028366
4 P21		0.4599	1.0582	1.4597	0.0033723
P22		0.4600	1.0468	1.4860	0.0008673
P23*		0.4600	1.0355	1.5123	0.0000007(MIN)
P24		0.4601	1.0242	1.5380	0.0007395
P25		0.4603	1.0102	1.5684	0.0036903
5 P26		0.4612	0.9511	1.5948	0.0044890
P27		0.4758	0.9500	1.5730	0.0018616
P28		0.4845	0.9387	1.5489	0.0002412
P29*		0.4932	0.9273	1.5246	0.0001964(MIN)
P30		0.5019	0.9159	1.5002	0.0017472
P31		0.5062	0.8935	1.4812	0.0047330
6 P32		0.5104	0.8709	1.4608	0.0061250
P33		0.5147	0.8475	1.4351	0.0018749
P34*		0.5190	0.8241	1.4095	0.0000698(MIN)
P35		0.5219	0.8072	1.3909	0.0002886
P36		0.5247	0.7904	1.3710	0.0018648
P37		0.5273	0.7743	1.3523	0.0046195
Group	mean	0.5200	0.8190	1.4030	
Total squared error value					0.06835
MIN represents minimum square error value from group mean * Alternatives representing the groups are P04, P11, P17, P23, P29, P34					

With reference to present planning problem, the suitable group for the planning problem is the group having the highest S/N ratio amongst the six groups. There are three possible types of situations in S/N ratio computations, viz., larger-the-better, smaller-the-better and nominal the best which are explained in brief.

S/N ratio for larger- the- better : $= -10 \log\left[\left(\frac{1}{n}\right) * \sum_{i=1}^{n} \left(\frac{1}{y_i^2}\right)\right]$ (1)

S/N ratio for smaller-the- better: $= -10 \log\left[\left(\frac{1}{n}\right) * \sum_{i=1}^{n} \left(y_i^2\right)\right]$ (2)

S/N ratio for nominal-the-best $= 10 \log\left[\frac{\bar{y}}{s}\right]^2$ (3)

where y_i is the i^{th} output and n is the total number of variations (number of strategies in each group), $\bar{y}$ is avera ge of y_i and s is standard deviation of data y_i. Here larger-the-better represents a characteristic which is as largeas possible (e.g., maximum net benefits), smaller-the-better represents a qual ity characteristic which is as small as p ossible (e.g., minimum cost), nominal-the-best represents a case in which a specified value is desired i.e., neither a smaller nor a larger value.

TOPSIS is based on the principle that the chosen alternative should have the shortest distance from the ideal solution and farthest distance from the negative ideal solution (Pom erol and Romero, 2000, Opricovic and Tzeng, 2004). The methodology consists of :

1. Computation of weighted normalised payoff matrix f_{ij} where i and j represent the alternative and criterion
2. Determine ideal f_j^+ and negative ideal f_j^- value for each criterion j
3. Calculate separation measures in n-dimensional Euclidean distance
4. The separation measure of each alternative i from the ideal solution is

$$D_i^+ = \sqrt{\sum_{j=1}^{n} (f_{ij} - f_j^+)^2} \quad (4)$$

5. The separation measure of each alternative i from the negative ideal solution is

$$D_i^- = \sqrt{\sum_{j=1}^{n} (f_{ij} - f_j^-)^2} \quad (5)$$

6. Computation of relative closeness C_i of each alternative i with referen ce to negative ideal measure D_i^- is

$$C_i = \frac{D_i^-}{(D_i^- + D_i^+)} \quad (6)$$

7. Rank the alternatives based on the C_i values. Higher the C_i value, better the alternative.

Various characteristics of S/N ratio method and TOPSIS are compared in Table 3.

Table 3. Comparative analysis of S/N ratio method and TOPSIS for important characteristics

Characteristic	S/N ratio method	TOPSIS
Criteria used for ranking	Only output criteria	All the criteria i.e., both input and output values in the payoff matrix
Uncertainty consideration in the method	Can be considered	Cannot be considered
Basis for ranking	Rank the grouping based on S/N ratio and then select the suitable alternative from each group	Select the suitable alternative from each group and rank them using the algorithmic procedure
Sensitivity analysis and parameters	Not required	Limited sensitivity analysis for TOPSIS.
Analysis of output	Easy to analyse and arrive at a suitable alternative	Some times difficult to arrive at a suitable alternative as it depends on outcome of sensitivity analysis.
Computational requirement	Very less	More as compared to S/N ratio

ANALYSIS OF RESULTS

S/N Ratio

S/N ratio method is used on the basis that strategies in a group are having similar characteristics with little or tolerable variations. In the present study, the factor of net benefits (outcome of slight variation of different values of input factors) is grouped under the larger-the-better category for S/N ratio computation. Table 4 presents S/N ratio values of net benefits for each group computed using equation 1. The group having the highest value of S/N ratio is the suitable group. Other groups are ranked based on S/N ratio.

It is observed from Table 4 that group G5 is the most suitable one with highest S/N ratio value of 184.141 (first rank). It may be observed that G4 is having a similar S/N ratio value with a small difference of 0.137. Rating of the groups G1 to G6 are in the order of 6, 5, 4, 2, 1, 3 (S/N ratio values are also computed using weighted normalised values of Table 2 and found that ranking of strategies remain same as before). After selecting the best/ suitable group, the square error values between group mean and the weighted normalised strategy values for each criterion in that group are calculated and presented in Table 2. The strategy that gives the minimum total square error value is chosen as the representative strategy for that group. For example the values of three criteria, labour employment, agricultural production and net benefits for P17 are 0.4391, 1.0672, 1.3722 and corresponding group mean for cluster group 3 are 0.4420, 1.0670, 1.3810. Then deviation (square error) of P17 with group mean is calculated as $[(0.4391-0.4420)^2 + (1.0672-1.0670)^2 + (1.3722-1.3810)^2] = 0.0000863$. The strategies P04/G1, P11/G2, P17/G3, P23/G4, P29/G5, P34/G6 of Table 2 having minimum total square error values of 0.0000014,0.0000009, 0.0000863, 0.0000007, 0.0001964, 0.0000698 are the representative ones of the six groups. Table 4 presents the representative payoff matrix of each group. Alternative strategies P29/G5 and P23/G4 which are ranked first and second are taken up for further analysis.

TOPSIS

Weighted normalised values presented in Table 2 for the chosen six strategies (presented with asterisk) are used for the computation of D_i^+, D_i^-, C_i. Ideal and negative ideal values (among chosen six strategies) are estimated from Table 5. Weighted normalised values, ideal and negative ideal values, D_i^+, D_i^-, C_i and ranking pattern are presented in Table 5. It is observed that G4/P23 and G5/P29 are in the first and second positions due to their higher C_i values of 0.8565, 0.7362. Sensitivity analysis is also performed by (1) choosing ideal and negative ideal values from 37 values and (2) normalisation method suggested by Opricovic and Tzeng (2004) for the TOPSIS method (for the data in Table 4). It is observed that C_i values are affected in both situations. However, there is no change in the ranking pattern. Further studies are targeted for more sensitivity analysis in terms of normalization methods which may affect ranking pattern. It is also observed that all the three criteria are involved while estimating the ranking pattern by TOPSIS even though net benefits are the only outcome. This is contrary to S/N ratio method where net benefits alone are considered while computing the S/N ratio which is simpler and flexible with no parameter due for sensitivity analysis. Table 1 presents the salient features of net benefits, agricultural production and labour employment of P23 and P29.

Table 4. Representative payoff matrix and S/N ratio values for groups

Strategy Number	Labour Employment (Million man days)	Agricultural Production (Million Tons)	Net Benefits (Million Rupees)	S/N ratio	Rank
G1 / P04	35.250	0.77718	1152.00	181.216	6
G2 / P11	36.300	0.77250	1301.80	182.281	5
G3 / P17	38.492	0.76386	1439.50	183.212	4
G4 / P23	40.331	0.74119	1586.50	184.004	2
G5 / P29	43.239	0.66374	1599.40	184.141	1
G6 / P34	45.500	0.58989	1478.70	183.349	3

Table 5. D_i^+, D_i^-, C_i and final ranks by TOPSIS method

Strategy Number	Labour employment	Crop Production	Net Benefits	D_i^+	D_i^-	C_i	Rank
G1 / P04	0.4021	1.0858	1.0981	0.4422	0.2617	0.3718	6
G2 / P11	0.4141	1.0792	1.2409	0.3025	0.2926	0.4916	5
G3 / P17	0.4391	1.0672	1.3722	0.1731	0.3682	0.6803	3
G4 / P23	0.4600	1.0355	1.5123	0.0785	0.4686	0.8565	1
G5 / P29	0.4932	0.9273	1.5246	0.1606	0.4482	0.7362	2
G6 / P34	0.5190	0.8241	1.4095	0.2859	0.3326	0.5378	4
Ideal	0.5190	1.0858	1.5246				
Negative ideal	0.4021	0.8241	1.0981				

Rank Correlation Coefficient Value

Kendall rank correlation coefficient is used in the present study to determine the measure of association between ranks obtained by S/N ratio and TOPSIS (Connolly and Sluckin, 1953). It is found that the value of correlation coefficient between S/N ratio and TOPSIS is 0.733. It is observed that correlation coefficient values are reasonable.

CONCLUSIONS

Two methods, namely, S/N ratio and TOPSIS are employed for evaluating and ranking irrigation planning strategies. These methods are applied to a case study of Sri Ram Sagar Project, India, for ranking the irrigation planning strategies. It is found that the two methods are showing the same two strategies as the potential ones (first and second best) for further analysis. It is also inferred that TOPSIS is less sensitive to the numerous parameters employed whereas in S/Nratio method no parameters are due for sensitivity analysis which is a boon, as the outcome expected would be robust.

REFERENCES

Aomar, R.A. 2002. A robust simulation-based multicriteria optimization methodology. *Proceedings of the 2002 Winter Simulation Conference, Institute of Electrical and Electronics Engineers, San Diego, CA*, Ed. Yucesan, E., Chen, C.H. , Snowdon, J.L., Charnes, J.M., 1931-1939.

Connolly, T.G. and Sluckin, W. 1953. *An introduction to statistics for the social sciences*. Cleaver-Hume Press Ltd, London.

Duckstein, L., Treichel, W. and Magnouni, S.E. 1994. Ranking ground-water management alternatives by multicriterion analysis. *Journal of Water Resources Planning Management*, *ASCE*, 120, 546-565.

Jain, A.K. and Dubes, R.C. 1988. *Algorithms for clustering data*. Prentice- Hall, Englewood Cliffs, NJ

Opricovic, S. and Tzeng, G.H.2004. Compromise solution by MCDM methods: a comparative analysis of VIKOR and TOPSIS. *European Journal of Operational Research*, 156, 445-455.

Pomerol, J.Ch. and Romero, S.B. 2000. *Multicriterion decision in management: principles and practice*. Kluwer Academic Publishers, Netherlands.

Raju, K.S. 1995. *Studies on multicriterion decision making methods and management of Irrigation systems*. PhD thesis, Indian Institute of Technology, Kharagpur.

Raju, K.S. and Nagesh Kumar, D. 1999. Multicriterion decision making in irrigation planning. *Agricultural Systems*, 62, 117-129.

Raju, K.S. and NageshKumar, D. 2010. *Multicriterion analysis in engineering and management.* Prentice Hall of India, New Delhi.

Ross, P.J. 2005. *Taguchi techniques for quality engineering*. Tata McGraw-Hill, New Delhi.

Saaty, T. L. and Gholamnezhad, H. 1982. High-level nuclear waste management: analysis of options. *Environmental Planning* 9, 181-196.