INDIAN INSTITUTE OF MANAGEMENT CALCUTTA

WORKING PAPER SERIES

WPS No. 702/ July 2012

A multi-criteria approach for railway project portfolio fund allocation

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Abstract: In an emerging economy, transport planners have a difficult task of allocating scarce and costly capital amongst the available shelf of railway projects to effectively meet the increasing demands for railway infrastructure. Hitherto, a single criterion such as IRR was being used for ranking and selection of railway projects; however of late, planners have realized the need to incorporate other economic and strategic criteria too in project portfolio selection. There is thus now a need for an analytical tool to assist the decision makers in systematically evaluating the options for optimal allocation of capital amongst railway projects, using various criteria simultaneously. This paper proposes a two-phase analytic Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)-Global Criteria approach for the purpose, wherein AHP is used to determine the weights of each criterion based on the planners' evaluation of their relative importance. A single objective function is then obtained using TOPSIS-Global Criteria approach, which is used to identify the optimal capital allocation amongst competing projects. The methodology is demonstrated on a test case of a shelf of railway projects to obtain the best project portfolio fund allocation within the available capital resources.

INTRODUCTION

The transport infrastructure, including the railways has evolved in emerging economies such as India, as a colonial legacy. The transport infrastructure was developed primarily to serve colonial commercial, military and administrative interests. For example, the Indian railway network was designed for exporting raw material such as cotton and jute through the port cities, as well as provides means for swift deployment of the colonial army and police in event of civil disturbances. Later, the connectivity of Indian railway network structure was broken at many places, owing to the partition of the country on attaining independence.

Following independence, the transport planners have had the difficult task of restoring the connectivity of the Indian railway network and correcting the imbalances in network density across the country (as given in Table 1). Railways have assumed the role of a primary mode of transport, since roads are underdeveloped in many parts of the country and air transport is un-economical for transport of passenger and goods.

Since railway transport is far more efficient than road transport, in terms of energy consumption and carbon footprint, transport planners favour the choice of rail transport mode over road transport. A recent report [1] argues for increasing the investment in Indian railway projects from current level of 40% of the total infrastructure investments to achieve an optimal modal logistics network for facilitating India's economic growth.

TABLE 1 Comparison of Railway Network in various Indian states

State	Route km per million population	Route km per 1000 sq km area	Route km per Rs.1000 crores Net State Domestic Product
Uttar Pradesh	53	36	19
Gujarat	103	27	14
Maharashtra	58	18	7
Tamil Nadu	145	31	10
Kerala	33	27	5
Punjab	89	43	12
West Bengal	49	44	11

Bihar	44	38	33
Assam	90	31	40

Source: calculated from data obtained from various sources [2], [3] and [4]

Transport planners routinely face dilemmas in trying to decide the priority of funding of the projects. Transport planners cannot solely rely on criteria such as rate of return or payback period to decide investments in new and existing projects. Other considerations also have to be taken into consideration. Different states vie to increase their transport infrastructure. Various industries lobby for improvement of transport infrastructure to facilitate either raw material movement or finished goods movement. Strategic interests require development of certain railway lines to facilitate troop movements. Again certain railway projects need to be taken up for development of backward areas of the country. These dilemmas are further accentuated with a large shelf of railway projects proposed for different considerations. In 2011-12, investment planning had to be done for 381 railway projects for 41 thousand km of railway network requiring a total investment of Rs.260 thousand crores [5].

Whilst there are diverse demands on funding railway projects from various quarters, the amount of funds available for investment in projects is quite limited. Since generation of funds from internal sources are inadequate, planners resort to market borrowings thereby increasing the cost of the investment capital. Under such situations, it might be judicious to invest the maximum amount of funds in high return projects so that these projects are completed as early as possible; the returns of these projects can then be used to fund the relatively low return projects. However, this delays the process of completion of projects which have low returns but might be essential due other considerations such as development of backward areas or for furthering strategic defence interests. These scenarios make the task of selection of projects for funding and the amount of funds that should be allocated for the projects extremely daunting.

Conventional capital budgeting techniques such as rate of return, payback period or net present value determine whether a project is worth investing, given its cost and revenue cash flows [6]. There is however no method available whereby a planner can decide the manner of allocation of scarce funds amongst competing projects using a number of conflicting objectives.

This paper proposes a method of allocating weights to conflicting objectives after eliciting opinions of transport planners, decision makers and stakeholders regarding the relative importance of each objective using the Analytic Hierarchy Process. These weights of multiple objectives are used to compute distance functions and convert a multi-criteria problem to a optimization problem with a single objective using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)-Global Criteria approach. The methodology is demonstrated on a case involving a number of projects, where the decision maker is required to take conflicting objectives into consideration while allocating funds for these projects.

The paper is organized as follows: the methodology section describes the TOPSIS-Global Criteria approach and the Analytic Hierarchy Process; followed by demonstration of the procedure using a test case; followed by discussions and conclusion.

METHODOLOGY

The problem of fund allocation amongst competing projects discussed in this paper satisfies the common characteristics of Multiple Criteria Decision Making (MCDM) problems, as given by Hwang and Yoon [7], since it has multiple objectives many of which conflict with each other.

In this paper we use the TOPSIS-Global Criteria approach methodology, along with Analytic Hierarchy Process to reduce the problem to a single objective function after eliciting opinion of decision makers on the ranking of the competing objectives.

TOPSIS Approach

TOPSIS was originally developed Hwang and Yoon [7] for solving multiple attribute decision making(MADM) problems, and extended to solve multiple objective decision making(MODM) problems by Lai et.al. [8]. The underlying principle of the methodology is that the chosen alternative should have the shortest distance from the Positive Ideal Solution (PIS) and the farthest distance from the Negative Ideal Solution (NIS).

We describe the TOPSIS methodology, considering a MODM problem as follows:

$$\text{max/min } [f_1(x), f_2(x), \ldots\ldots, f_k(x)]$$
$$\text{s.t. } x \in X = \{x \mid g_i(x)\{\geq, =, \leq\}0, i = 1,2, \ldots\ldots, m\}$$

where,

$$f_j(x) = \text{Benefit objective for maximization, } j \in J$$
$$f_i(x) = \text{Cost objective for minimization, } i \in I$$

The steps of the TOPSIS methodology are as follows:

(i) Obtain the PIS (f^*) and NIS (f^-), which are given by:

$$f^* = \{\max_{x \in X} (\text{or min}) f_j(x) (\text{or } f_i(x)), \forall j (\text{and } i)\}$$
$$f^- = \{\min_{x \in X} (\text{or max}) f_j(x) (\text{or } f_i(x)), \forall j (\text{and } i)\}$$

(ii) Using the PIS and NIS, the following distance functions are obtained:

$$d_p^{PIS} = \left\{ \sum_{j \in J} w_j{}^p \left[\frac{f_j^* - f_j(x)}{f_j^* - f_j^-} \right]^p + \sum_{i \in I} w_i{}^p \left[\frac{f_i(x) - f_i^*}{f_i^- - f_i^*} \right]^p \right\}^{1/p}$$

$$d_p^{NIS} = \left\{ \sum_{j \in J} w_j{}^p \left[\frac{f_j(x) - f_j^-}{f_j^* - f_j^-} \right]^p + \sum_{i \in I} w_i{}^p \left[\frac{f_i^- - f_i(x)}{f_i^- - f_i^*} \right]^p \right\}^{1/p}$$

Where, $w_t, t = 1,2, \ldots\ldots, k$ are the relative importance (or weights) of the objective functions, obtained by the Analytic Hierarchy Process (AHP) described later in this section, and *p* is the distance parameter. We use *p*=2 in this paper.

(iii) We solve the problem $\min d_p^{PIS}(x)$,s.t. $x \in X$ to obtain the solution x^P and $\left(d_p^{PIS}\right)^*$=min $d_p^{PIS}(x)$

(iv) We solve the problem $\max d_p^{NIS}(x)$,s.t. $x \in X$ to obtain the solution x^N and $\left(d_p^{NIS}\right)^*$=max $d_p^{NIS}(x)$

(v) We obtain $\left(d_p^{PIS}\right)' = d_p^{PIS}(x^N)$ and $\left(d_p^{NIS}\right)' = d_p^{NIS}(x^P)$

(vi) We solve the following problem to obtain the solution to the MODM problem:

$$\max \alpha,$$
$$\frac{d_p^{PIS}(x) - \left(d_p^{PIS}\right)^*}{\left(d_p^{PIS}\right)' - \left(d_p^{PIS}\right)^*} \geq \alpha$$
$$\frac{\left(d_p^{NIS}\right)^* - d_p^{NIS}(x)}{\left(d_p^{NIS}\right)^* - \left(d_p^{NIS}\right)'} \geq \alpha$$
$$x \in X$$

Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is a MODM technique used to rank a finite set of pre-determined alternatives [9]. In this process, the decision makers are asked to specify the preferences among the various alternatives on each criteria and among criteria themselves by pair-wise comparison scheme. A pair of factors can either be two alternatives on each criteria or two criteria themselves. The decision maker is requested to specify his preference for one factor over another in a ratio scale.

The preferences are given on a ratio scale with n points 1,2,….,n, where each point represents a level of importance of one factor over another in the pair-wise comparison scheme. The terminal points 1 and n of the ratio scale represent equal importance and maximum importance respectively. For example, considering two objectives X and Y, the decision maker may judge X as m times more important than objective Y. This implies that the decision maker considers Y as $1/m$ times more important than X. If there are q objectives, we can get a q x q response matrix **A** of the decision maker's responses. The diagonal elements of the response matrix **A** will be 1, since the relative importance of any objective to itself is 1. Let the pair-wise comparison of factor f_i over f_j on the ratio scale be S_{ij}, where i,j =1,2,3..,q. The elements of the normalized response matrix $\mathbf{A_{norm}}$ are given by $S'_{ij} = \frac{S_{ij}}{\sum_{i=1}^{q} S_{ij}}, \forall j = 1,2, \dots, q$. The normalized weight w_i of each objective f_i is given by $\frac{\sum_{j=1}^{q} S'_{ij}}{q}, \forall i = 1,2, \dots, q$, which can be represented by a 1 x q weight matrix **w**.

The consistency of the decision maker's responses is checked by suitable measures developed for the purpose. If the inconsistency is very high, the decision maker is required to specify the preferences again. Once an acceptable level of consistency is reached, these preferences are then combined to find the overall ranking of the criteria. The consistency of responses are determined by the consistency ratio (COR) as follows.

TABLE 2 Random Consistency Numbers

Size of Matrix q	1	2	3	4	5	6	7	8	9	10
Random Consistency Number	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

The product of response matrix **A** and transpose of weight matrix **w** is calculated. The Consistency Index (CI) is then given by $\frac{\frac{1}{q}\sum_{i=1}^{q}\frac{i^{th}\text{ entry in }\mathbf{Aw^T}}{i^{th}\text{ entry in }\mathbf{w^T}} - q}{q-1}$. The Consistency Ratio (COR) is determined by dividing the value of CI by the Random Consistency Number of the same size matrix. The random consistency numbers for matrices of different sizes are given in Table 2 [9]. A value of COR less than 10% is considered acceptable. In that case the ranking of the objectives is given by the Normalized Weights(w_i).

DEMONSTRATION OF METHODOLOGY

Let us take a situation, where only a limited amount of funds are available annually for allocation amongst various projects listed in Table 3. The transportation infrastructure planners wish to determine the amount of funds that are to be allocated to each project every year out of the limited amount of funds available. Thus if Rs.100 crores are allocated each year, on an average, for a project with an estimated cost of Rs.500 crores, the project will take 5 years to complete. It has been assumed that the same amount of funds is allocated to a project every year for the purpose of modelling. In reality, the funds required will vary from year to year for any project; thus the average annual fund requirement can be considered as the decision variable of this problem.

Even if Rs.500 crores are allocated in a single year for a project with an estimated cost of Rs.500 crores, the project cannot be completed and commissioned in a single year due to a minimum time period required for completion of all the activities comprising the project work. Therefore, for the purpose of this model, we assume that all projects will require a minimum time of 3 years for completion and commissioning.

We assume that a total of Rs.900 crores are available for allocation each year amongst all the projects. Further, we assume that the transport planners require the project construction and commissioning be completed within a maximum of 25 years over a 30-year planning horizon.

TABLE 3 Details of Projects under consideration

Project Sl.No.	Total funds required for completion (Rs.crores)	Annual revenue from the project after commissioning (Rs.Crores)	Characteristics of the project
1	300	50	Gauge conversion from Metre Gauge to Broad Gauge of existing line
2	1250	100	Port connectivity augmentation project Project can commences only after project 1 is commissioned
3	900	200	Port connectivity augmentation project
4	600	100	Doubling of single line
5	1900	50	Projects located in north-east
6	800	60	Projects located in north-east

Once a project is commissioned, the railway freight and passenger traffic will commence running on the particular stretch of railway and will start generating revenue. For example, if project 4 is completed in 5 years, it will generate revenue of Rs.100 crores for the remaining 25 years of a 30-year planning horizon. The estimated revenue earnings for each project is indicated in Table 3.

AHP Methodology

Let us assume that the planners have to decide the fund allocation based on a combination of four different competing objectives:

i. Objective 1:Maximize the revenue generation over a 30-year planning horizon.
ii. Objective 2:Minimize the time of completion of all projects
iii. Objective 3:Minimize the time of completion of projects located in the north east
iv. Objective 4:Minimize the time of completion of port connectivity augmentation projects

Let the transport planners rate the relative importance of the objectives in a pair-wise comparison response matrix **A**, as given in Table 4. Here the entry 5 in the first row indicates that the planners' rate objective 1 as 5 times more important than objective 3.

TABLE 4 Response Matrix

	Objective 1	Objective 2	Objective 3	Objective 4
Objective 1	1	2.5	5	4
Objective 2	0.4	1	2	1
Objective 3	0.2	0.5	1	0.5
Objective 4	0.4	1	2	1

In order to obtain the weight w_j for each objective and check the consistency of the planner's ratings, the following procedure is adopted:

(a) Divide each entry by the sum of the entries in the column. Thus entry 5 in the first row is divided by 10. We thus obtain a modified response matrix in Table 5 given below.

TABLE 5 Modified Response Matrix

	Objective 1	Objective 2	Objective 3	Objective 4
Objective 1	0.54	0.50	0.50	0.62
Objective 2	0.22	0.20	0.20	0.15
Objective 3	0.11	0.10	0.10	0.08
Objective 4	0.14	0.20	0.20	0.15

(b) We obtain the weight w_j for each objective as a single row matrix **w** in Table 6 by taking the average of entries in the corresponding rows of Table 5.

TABLE 6 Objective weights

	Objective 1	Objective 2	Objective 3	Objective 4
Weight w_j	0.5	0.2	0.1	0.2

(c) We compute the product of the matrix of entries in Table 5 with the transpose of single row matrix **w** in Table 6.

$$\mathbf{A}\mathbf{w}^{\mathbf{T}} = \begin{bmatrix} 0.54 & 0.50 & 0.50 & 0.62 \\ 0.22 & 0.20 & 0.20 & 0.15 \\ 0.11 & 0.10 & 0.10 & 0.08 \\ 0.14 & 0.20 & 0.20 & 0.15 \end{bmatrix} \begin{bmatrix} 0.5 \\ 0.2 \\ 0.1 \\ 0.2 \end{bmatrix} = \begin{bmatrix} 2.19 \\ 0.77 \\ 0.39 \\ 0.69 \end{bmatrix}$$

(d) We compute the Consistency Index (CI) as $\frac{\frac{1}{4}\sum_{i=1}^{4}\frac{ith \text{ entry in } \mathbf{Aw^T}}{ith \text{ entry in } \mathbf{w^T}}-4}{4-1}$=0.009253. The Consistency Ratio (COR) works out to 0.0103, considering a Random Consistency Number of 0.9 obtained from Table 2 (for a matrix size of 4). Since the COR is less than 10%, the planners ratings are consistent and therefore acceptable.

Multi-objective Model

The multi-objective NLP model for the problem is formulated as follows:

Indices used:

i this index is used for projects, i=1 to 6

Notation for data elements:

K_i = total cost of project i

R_i = annual revenue generated by project i after construction and commissioning

U = total funds available for allocation each year amongst all the projects

Decision variables:

m_i = annual funds allocated to project i

c_i = number of years required to complete and commission project i

n_i = number of years of revenue generation in a 30-year planning horizon

The objective functions are:

$$\max f_1 = \sum_{i=1}^{6} R_i n_i$$

$$\min f_2 = c_1 + c_2 + c_3 + c_4 + c_5 + c_6$$

$$\min f_3 = c_5 + c_6$$

$\min f_4 = c_2 + c_3$

Subject to the constraints:

$c_i = \frac{K_i}{m_i}, \forall i = 1,2, \dots ,6$ (1)

$3 \leq c_i \leq 25, \forall i = 1,2, \dots ,6$ (2)

$n_i = 30 - c_i, \forall i = 1,3,4,5,6$ (3)

$n_2 = 30 - c_1 - c_2$ (4)

$\sum_{i=1}^{6} m_i \leq U$ (5)

Explanation of the constraints: Constraint (1) determines the number of years required to construct and commission a project, depending on the annual funds allocations. Constraint (2) places upper and lower bounds on the number of years required for constructing and commissioning a project. Constraint (3) determines the number of years that a project will generate revenue after construction and commissioning in a 30-year planning horizon. Constraint (4) determines the number of years that Project 2 will generate revenue after construction and commissioning in a 30-year planning horizon, given that Project 2 construction can commence only after construction and commissioning of Project 1. Constraint (5) restricts the total annual fund allocation for all projects to the total funds available every year.

TOPSIS Approach

The multi-objective model is solved considering each objective function to obtain the PIS (f^*) and NIS (f^-) of each objective, which are given in Table 7.

TABLE 7 PIS and NIS for all objectives

	Objective f_1	Objective f_2	Objective f_3	Objective f_4
PIS	13347	36	7	6
NIS	2300	130	50	50

The following distance functions are obtained using these values of PIS and NIS.

$$d_2^{PIS} = \left\{0.5^2 \left[\frac{13347-f_1}{13347-2300}\right]^2 + 0.2^2 \left[\frac{f_2-36}{130-36}\right]^2 + 0.2^2 \left[\frac{f_3-7}{50-7}\right]^2 + 0.2^2 \left[\frac{f_4-6}{50-6}\right]^2\right\}^{1/2} \quad (6)$$

$$d_2^{NIS} = \left\{0.5^2 \left[\frac{f_1-2300}{13347-2300}\right]^2 + 0.2^2 \left[\frac{130-f_2}{130-36}\right]^2 + 0.2^2 \left[\frac{50-f_3}{50-7}\right]^2 + 0.2^2 \left[\frac{50-f_4}{50-6}\right]^2\right\}^{1/2} \quad (7)$$

We solve the problem $\min d_2^{PIS}$ to obtain the solutions x^P , $\left(d_p^{PIS}\right)^*$=min $d_p^{PIS}(x)$ and $\left(d_p^{NIS}\right)' = d_p^{NIS}(x^P)$, using the constraints (1) to (5) and (8) to (11). We obtain $\left(d_p^{PIS}\right)^*$= 0.08 and $\left(d_p^{NIS}\right)'$= 0.94.

We solve the problem max $d_p^{NIS}(x)$ to obtain the solutions x^N , and $\left(d_p^{NIS}\right)^*$=max $d_p^{NIS}(x)$ and $\left(d_p^{PIS}\right)' = d_p^{PIS}(x^N)$, using the constraints (1) to (5) and (8) to (11). We obtain $\left(d_p^{NIS}\right)^*$=0.95 and $\left(d_p^{PIS}\right)'$=0.09.

$f_1 = \sum_{i=1}^{6} R_i n_i$ (8)

$f_2 = c_1 + c_2 + c_3 + c_4 + c_5 + c_6$ (9)

$f_3 = c_5 + c_6$ (10)

$f_4 = c_2 + c_3$ (11)

We thus solve the multi-objective problem, by formulating a single objective function maximize α, with two constraints (in addition to the constraints (1) to (11) listed above):

$$\frac{d_2^{PIS}-0.08}{0.09-0.08} \geq \alpha \qquad (12)$$

$$\frac{0.95-d_2^{NIS}}{0.95-0.94} \geq \alpha \qquad (13)$$

The optimal fund to be allocated annually and time required for completion and construction (in years) of each project is thus obtained, as listed in Table 8.

TABLE 8 Optimal fund allocation and completion time

	Project 1	Project 2	Project 3	Project 4	Project 5	Project 6
optimal annual fund allocation (Rs.crores)	88	195	200	107	185	123
time required for completion (years)	3.4	6.4	4.5	5.6	10.3	6.5

The time required for completion (in years) obtained using the above methodology, for different objective weight combinations and different total funds available for allocation each year amongst all the projects is given in Table 9. The net cash flow indicates the total earnings over the 30-year planning horizon minus the costs of the projects; thus net cash flow will be low whenever commissioning of high revenue earning projects (such as Project 3) are delayed.

TABLE 9 Completion time and Net cash flows for different scenarios

	Weights	Proj 1	Proj 2	Proj 3	Proj 4	Proj 5	Proj 6	Net cash Flow
total funds available for allocation each year=Rs.600 crores	w1=0.25;w2=0.25;w3=0.25;w4=0.25;	5.9	9.9	7.6	9.3	13.1	8.4	5560
	w1=0.3;w2=0.2;w3=0.4;w4=0.1;	6.0	12.0	8.6	9.6	11.3	7.3	5279
	w1=0.1;w2=0.1;w3=0.4;w4=0.5;	9.3	8.7	7.2	14.6	12.2	7.9	4805
	w1=0.8;w2=0.1;w3=0.05;w4=0.05;	4.4	10.3	6.5	7.5	16.6	10.1	5859
	w1=0.05;w2=0.8;w3=0.05;w4=0.1;	5.4	10.2	8.5	7.7	13.2	8.6	5587
	w1=0.05;w2=0.05;w3=0.8;w4=0.1;	11.3	18.7	17.4	23.1	7.3	4.7	1047
	w1=0.05;w2=0.05;w3=0.1;w4=0.8;	12.2	5.4	4.6	19.3	25.0	20.1	3393
total funds available for allocation each year=Rs.900 crores	w1=0.25;w2=0.25;w3=0.25;w4=0.25;	4.1	6.6	5.0	6.5	8.6	5.5	7362
	w1=0.3;w2=0.2;w3=0.4;w4=0.1;	4.1	8.0	5.8	6.6	7.5	4.8	7170
	w1=0.1;w2=0.1;w3=0.4;w4=0.5;	6.5	5.8	4.7	10.2	8.1	5.2	6810
	w1=0.8;w2=0.1;w3=0.05;w4=0.05;	3.0	6.9	4.4	5.0	10.9	6.7	7586
	w1=0.05;w2=0.8;w3=0.05;w4=0.1;	3.6	6.8	5.6	5.2	8.8	5.7	7410
	w1=0.05;w2=0.05;w3=0.8;w4=0.1;	8.9	11.7	9.3	13.9	5.1	3.3	4844
	w1=0.05;w2=0.05;w3=0.1;w4=0.8;	8.1	3.9	3.3	12.7	14.4	9.2	6257
total funds available for allocation each year=Rs.1200 crores	w1=0.25;w2=0.25;w3=0.25;w4=0.25;	3.2	4.9	3.8	5.0	6.4	4.1	8267
	w1=0.3;w2=0.2;w3=0.4;w4=0.1;	3.2	6.0	4.3	5.0	5.5	3.5	8116
	w1=0.1;w2=0.1;w3=0.4;w4=0.5;	5.1	4.3	3.5	8.0	6.1	3.9	7814
	w1=0.8;w2=0.1;w3=0.05;w4=0.05;	3.0	5.0	3.2	3.7	7.9	4.9	8407
	w1=0.05;w2=0.8;w3=0.05;w4=0.1;	3.0	4.9	4.1	3.9	6.6	4.3	8302
	w1=0.05;w2=0.05;w3=0.8;w4=0.1;	6.3	7.8	6.2	9.9	3.7	3.0	6726
	w1=0.05;w2=0.05;w3=0.1;w4=0.8;	5.4	3.0	3.0	8.5	8.8	5.7	7713
total funds available for allocation each year=Rs.1500 crores	w1=0.25;w2=0.25;w3=0.25;w4=0.25;	3.0	3.8	3.0	4.0	5.0	3.2	8769
	w1=0.3;w2=0.2;w3=0.4;w4=0.1;	3.0	4.7	3.4	3.9	4.2	3.0	8667
	w1=0.1;w2=0.1;w3=0.4;w4=0.5;	4.1	3.4	3.0	6.5	4.7	3.1	8427
	w1=0.8;w2=0.1;w3=0.05;w4=0.05;	3.0	3.7	3.0	3.0	5.8	3.5	8836
	w1=0.05;w2=0.8;w3=0.05;w4=0.1;	3.0	3.9	3.3	3.1	5.2	3.4	8795
	w1=0.05;w2=0.05;w3=0.8;w4=0.1;	4.4	5.3	4.3	6.9	3.0	3.0	7975
	w1=0.05;w2=0.05;w3=0.1;w4=0.8;	3.5	3.0	3.0	5.4	5.4	3.5	8612

It will be observed from the above table, that (a) for all instances with w1=0.8 (maximization of revenue over 30-year planning horizon), the net cash flow is maximum; (b) for all instances with w2=0.8 (minimum completion time of all projects), the sum of completion time of all projects is minimum; (c) for all instances with w3=0.8 (minimum completion time of north east projects), the sum of completion time of Projects 5 and 6 is minimum; (d) for all instances with w4=0.8 (minimum completion time of port connectivity projects), the sum of completion time of Projects 2 and 3 is minimum. Further it may be noted that with the increase in annual funds allocation from Rs.600 crores to Rs.1500 crores, the time of completion of projects reduces and the net cash flow has increases correspondingly.

DISCUSSION & CONCLUSION

The method demonstrated in this paper takes into account multiple objectives and also recognizes the weight accorded by the planners to the multiple objectives. The method also takes into consideration both the cost and revenue of a project in deciding the allocation of funds to different projects across the planning horizon.

This method can also be used for other areas which require scarce resource allocation under competing objectives.

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