Application of Bootstrap Technique and Genetic Algorithm for Resource Optimization of Bridge Projects

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Abstract— Bridge construction consists of resources which range from simple to complex in nature. Resources include information, equipments, labor, money and time. In order to optimize resources like manpower, equipments, money and materials efficient resource management is necessary. Thus, the present research work aims at using bootstrap technique to identify and evaluate the control variables for resource management under uncertainty in bridge construction projects. Also, resource optimization model for bridge project using genetic algorithm is developed. The benefit of using proposed model is to search for an optimum set of resources that will optimize both cost and time, under various constraints related to desired productivity, work conditions, and resource availability limit. Efficient use of project resources will reduce overall construction cost and will increase the work productivity of the project resources.

Key words— Resource optimization, Bootstrap technique, Genetic algorithm, Bridge projects

I. INTRODUCTION

Resource management is a difficult task in bridge construction projects due to its complicated nature, huge budget involved, complex schedule, difficulties associated with modelling critical activities in bridge construction, and the limitation of traditional optimization tools to deal with large-sized problems. It is widely recognized that low labour productivity, improper utilization of equipments and resource uncertainty are among the critical problems facing the bridge construction industry in terms of resource management. This results into inefficient resource utilization and inadequate planning which has a tremendous impact on construction costs and time. Hence identifying and evaluating such control variables under uncertainty is essential. With manpower and machinery accounting for the majority of construction cost, it is apparent that proper resource utilization strategies and better utilization of existing resources are needed to improve work productivity under different constraints.

Considering the complexity of bridge projects in terms of project duration, construction cost and productivity, there is need of resource optimization model that considers all requirements of resource management all together. The power and simplicity of the proposed model and its optimized performance hopefully will encourage project experts to utilize it in the planning and execution of large infrastructure projects. It can be used to provide the optimum number of resource quantities, workload, assignment strategies and accordingly to improve overall productivity. Thus the present research aims at developing a hybrid approach model for resource management of bridge projects using genetic algorithm and bootstrap technique.

II. LITERATURE REVIEW

A number of resource optimization models and algorithms have been developed to reduce the level of fluctuations in resource utilization and their negative impact on construction productivity, time and cost.

Chan et al. (1996) proposed a resource leveling method based on a genetic algorithm scheduler. The performance of the genetic algorithm scheduler was compared against heuristic methods under various resource availability profiles. It was found that genetic algorithm shares one drawback with heuristic methods that it is not possible to know if an optimal result has been obtained. Hegazy (1999) presented an optimization model using heuristic methods and genetic algorithms. Moments are calculated considering resource histogram. Moment around the horizontal axis indicates resource fluctuation while moment around the vertical axis indicates resource utilization period. However, the method did not include minimization of project cost and did not yield optimum solutions. Hegazy and Kassab (2003) have developed resource optimization model by combining a flow chart based simulation tool and genetic algorithm. Further, genetic algorithm-optimized simulation models were integrated with project management software to form a hierarchical planning system.

Jaskowski and Sobotka (2006) used evolutionary algorithms to solve the problem of minimizing construction project duration in deterministic conditions, with in-time changeable and limited accessibility of renewable resources like workforce, machines, and equipment. Doulabi et al. (2011) proposed hybrid genetic algorithm to tackle multiple resource-leveling problems allowing activity splitting. The cost of activity splitting and the benefits of resource leveling obtained by splitting are compared. Khaled and Kandil (2005) have designed the model to transform traditional 2-D time- cost tradeoff analysis to an advanced 3-D time-cost-quality tradeoff. Furthermore, Dho and Khaled (2011) developed a multiobjective resource allocation model with construction schedules.

Reviewing the literature for about past two decades, it has been observed that there is need of resource optimization model that considers all requirements of resource management all together in terms of project duration, construction cost and productivity, based on the advantages of genetic algorithms.

Thus the present research work aims at using bootstrap technique to identify and evaluate the control variables for resource management under uncertainty in bridge construction projects. Also, a hybrid model for resource management of bridge project using genetic algorithm and bootstrap technique will be developed.

III. CONCEPTUAL FRAMEWORK

Genetic Algorithm

A genetic algorithm is the evolution process: survival of the fittest. The evolution process predicts the survival and characteristic of the offsprings on the basis of knowing the characteristics of their parents. A genetic algorithm is an optimization procedure that operates on sets of design variables. Each set is called a string and it defines a potential. Each string consists of a series of characters (binary or digital numbers) representing the values of the discrete design variables for a particular solution. The fitness of each string is a measurement of the performance of the design variables as defined by the objective function and the constraints.

Each individual solution is represented by a single string like entity called a chromosome. A chromosome typically consists of a number of genes, which may be visualized as boxes arranged in a linear fashion as shown in figure below. Two attributes are associated with each gene: its position and its contents which code for a solution.

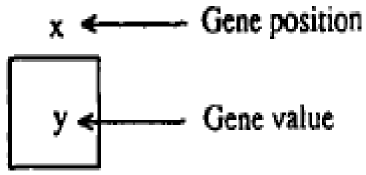

Fig.1 Chromosome representation

Goldberg (1999) has given five steps to creating a genetic algorithm:

1. Formation of the chromosome structure (sets of design variables) suitable for the problem on hand.

2. Selection of the evaluation criteria (objective function).
3. Generation of an initial population of chromosomes (initial solutions).
4. Selection of an offspring generation mechanism (process to generate new potential solutions).
5. Preparation of the procedure code to apply genetic operators to generate the next generation of solution strings.

Simplest form of genetic algorithm consists of three operations:

- Reproduction
- Crossover
- Mutation

Torres et al. (2010) have given the general description of genetic algorithm which is given as

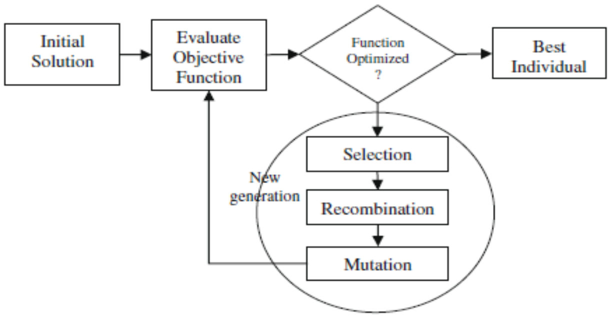

Fig.2 General description of genetic algorithm (Torres et al., 2010)

The fitness of each string is evaluated by performing system analysis to compute the value of the objective function. If the solution violates any of the constraints, the value of the objective function is penalized.

Genetic algorithm system can be represented by the following pseudo-code,

```
Begin:
Initialize (old-population)
Evaluate (old-population)
    Do (until generation = maximum number of generations)
        Reproduction (old-population);
        Crossover (new-population);
        Mutation (new-population);
        Old-population = new-population;
    End;
End;
```

Bootstrap Technique

Bootstrap technique is one of the well-known resampling techniques. The bootstrap technique is an extremely attractive tool as it requires few assumptions for modeling and analysis. It is essentially a computer based technique that substitutes considerable amounts of computation, which can be automated, in place of theoretical analysis. This technique has been used to solve many problems that are too complicated for traditional statistical analysis. In comparison with jackknife and cross-validation techniques, bootstrapping gives more accurate results and is more robust and popular.

Efron and Tibshirani (1993) found that the bootstrap technique outperforms other techniques in many cases for estimating distributions and confidence intervals. Moreover, applications of the bootstrap technique are found in numerous industrial fields, including machine learning, hydrology, geology, model selection; signal processing, risk management and cost management. In addition, from a theoretical point of view, bootstrapping is likely to be more efficient because jackknife and cross-validation techniques use limited information about a statistic.

Hassan et al. (2011) found that bootstrap techniques produce more accurate inferences for comparing parametric techniques and are an alternative when the underlying parametric assumptions are not considered.

Risk data set sizes and expert's judgments are not usually sufficient for analyzing significant risks in bridge construction projects; moreover, the statistical distributions for risk parameter estimates are usually unknown. Standard parametric statistical techniques cannot provide appropriate solutions for cases with small data sets or unknown distributions. It can be solved by non parametric techniques like bootstrap technique.

IV. RESEARCH METHODOLOGY

The control variables were identified through past experience of similar projects and in consultation with top management of two organizations located in a metro city like Mumbai and a mega city like Ahmedabad in India. The identified control variables are mentioned hereunder:

(i) Land acquisition & resettlement issues
(ii) Approvals & permit issues
(iii) Drawing/design availability
(iv) Tender document issues
(v) Co-ordination issues
(vi) Financial management issues
(vii) Materials management issues
(viii) Equipment management issues
(ix) Labor management issues
(x) Organization structure issues
(xi) Safety management issues
(xii) Project characteristics
(xiii) Quality management issues
(xiv) Other issues

The questionnaire comprised of questions pertaining to the uncertainties in the different activities associated and involved in construction of a bridge project. These uncertainties are primarily expressed in form of control variables. The responses were expected in form of probability of occurrence (P) and impact for the corresponding uncertainty (I). Out of a target sample size of 65 respondents, 40 have responded to the study.

Respondents for this survey included project managers, project engineers, site engineers, safety engineers, quality control engineers, design engineers and consultants. Then, non parametric bootstrap technique is used to analyze these control variables and find out severe control variables affecting proper resource management. The output of bootstrap technique i.e. severe control variables affecting proper resource management are considered while developing a resource optimization model using genetic algorithm.

With the use of primary data collected from site pertaining to the resources i.e. 4M- data related to manpower, material, machinery and money involved in different site activities of the bridge project and considering the related severe control variables, a genetic algorithm based resource optimization model is developed.

The benefit of using proposed model is to search for an optimum set of resources that will optimize both cost and time, under various constraints related to desired productivity, work conditions, and resources availability limits. The proposed model would also reduce the resource variability.

V. CASE STUDY

Case study considered for this research work for formulation and development of the hybrid model for resource management of bridge projects using genetic algorithm and bootstrap technique is a bridge project in Mumbai, India. The brief project details are given in table 1.

Table 1: Case Study Project Details

Project salient features	Description
Project	Design and construction of flyovers at Amar Mahal Junction connecting to Santacruz Chembur Link-Road with Eastern Express Highway
Client	Mumbai Metropolitan Region Development Authority (MMRDA)
Contractor	J Kumar Infra Projects Ltd.
Consultant	M/s Technogem Consultants Pvt. Ltd.
Type of contract	Lump sum contract
Project cost	INR 764.1 Million ($ 11.76 Million)
Project duration	22 months

Resources data related to manpower, materials, machinery and money for different activities involved the construction of the above bridge project were collected. Following is specimen of data collected for the piling activity. All the piles are cast-insitu bored piles with typical diameter of 1.2m and soil depth of about 12m. There are 5 piles in a group and a pier is standing on the group of 5 piles. There are 12 piers and thus the total numbers of piles are 60. The strata comprises of soil upto a depth of 9.5m and rock chiselling need to be done upto about 6m. The typical grade of concrete used in piles is M 40. The data collected about the pile cycle time of a typical pile is presented in table 2.

Table 2: Time cycle of a typical pile

Sub-activities of piling activity	Duration
Identification and shifting of utility services	2 days
Positioning tripod	2 hours
Setting out	2hours
Boring (12 m depth)	8 hours
Chiseling (6 m @ 0.1m /hour)	60 hours
Cage lowering	2 hours
Tremie pipe-lowering/flushing	2 hours
Concreting	3 hours
Removal of Tremie pipe	2 hours
Total time for piling	**81 hours**

Table 3: Manpower deployed for a typical pile construction

Sub activity	Skilled labor (Nos.)	Unskilled labor (Nos.)	Others (Nos.)
Cage formation	3	6	1 supervisor 1 engineer 1 welder 1Hydra operator
Boring	2	4	1 supervisor 1 welder 1Rig operator
Concreting	5	8	1 supervisor 1 engineer

Table 4: Equipments deployed for a typical pile construction

Activity	Equipments
Excavation	Hydraulic excavator (Ex-200)-1no. Dumper (5 cum capacity) -2 nos.
Boring	Hydraulic Rig soil auger -1no.
Reinforcement	Bar bending & cutting machine-1no Trailor for shifting / transporting-1no Hydra for cage lowering-1no.
Concreting	Batching plant (60 cum / hr capacity) Concrete transit mixers-2nos. Concrete pumps (with pipe line) -1no. Electric vibrator with needle -1 no.

VI. DATA ANALYSIS

Bootstrap Technique

To do the re-sampling, Stat Add-in of Excel software known as "Bootstrap BCA" is used. The original sample was compared with the bootstrapped resample of the B-replication of the data provided by Excel. The sampling of probability (P1 ,P2,..., P30) and impact (I1, I2,…, I30) with replacement was repeated many times (i.e., B times), each time producing bootstrap estimates of probability and impact.

In other words, the original samples were re-sampled with different B values until the confidence intervals for the criteria of control variables reached stability. This convergence occurred for the lower bound and upper bound of control variable after B = 250 in this case. Therefore, re-sampling with B = 250 is the best strategy for ranking the control variable according to the approach. The lower bound and upper bound of the confidence interval for the probability and impact criteria were calculated for each control variable.

Interval Score

To increase accuracy, interval numbers from the bootstrap technique are used to describe and treat the uncertainty of the control variable-ranking problem. The interval numbers of P and I criteria for the significant control variable are considered, on the basis of the 250-replication.

The interval score (IS) for each control variable under the probability and impact criteria are calculated as follows:

$$IS = \text{Probability (P)} \times \text{Impact (I)} \quad (1)$$

Final Ranking

After determining the interval score for each control variable in interval form, we must rank them to find the highest severity. In other words, considering two interval numbers, there is necessity to determine which risk element is greater or smaller than the other. Here, the distance technique is used.

To illustrate comparisons between ISj (j=1, 2,..…. 80), the calculations of the j'th control variable is as follows:

For interval numbers ISj, the value of the ideal score was determined first. The ideal score (IS*) is the highest value of the lower bound and upper bound of the confidence interval, thus IS* = [1; 1] was considered. Then the distance between IS* and ISj is calculated by using the equation stated below :

$$D(ISj, IS^*) = \sqrt{(x_1-1)^2 + (y_1-1)^2} \quad (2)$$

where j = 1, 2,…..... 80

A lower value of the distance between IS* and ISj indicates a higher rank and priority of that j'th control variable in terms of severity. Therefore, the final rankings are based on the interval computations.

Severe Control Variables

As per the principle of distance technique, lesser the distance between interval score of control variable and ideal score, more severe is the impact of that control variable on successful resource management in bridge construction project. As a part of sample analysis, for control variable, "improper materials management"

Confidence intervals for bootstrapped re-samples,

For 250 replications with B = 250, α = 5%

For probability criteria: BCA LCL 0.281 BCA UCL 0.394

For impact criteria: BCA LCL 0.493 BCA UCL 1.812

Interval Score (IS),

$IS(x_1) = P * I = 0.281*0.493 = 0.139$

$IS(y_1) = P * I = 0.394*1.812 = 0.713$

Distance from IS*,

$$D(ISj, IS^*) = \sqrt{(x_1-1)^2 + (y_1-1)^2}$$

$$= \sqrt{(0.139-1)^2 + (0.713-1)^2} = 0.908$$

Same calculations were carried out for all the control variables. Based on observation from analyzed data, following control variables are found to be severe and has major impact on bridge project objectives in terms of successful resource management.

1. Improper material management
2. Delayed payment on contract & extras
3. Change in scope / extra items
4. Approvals from concerned authorities
5. Improper utilization of equipments

Below figure shows the graph of Interval Score (IS) for each control variable with respect to lower and upper confidence interval. Lesser the distance from ideal score IS* (1,1), more severe is the control variable.

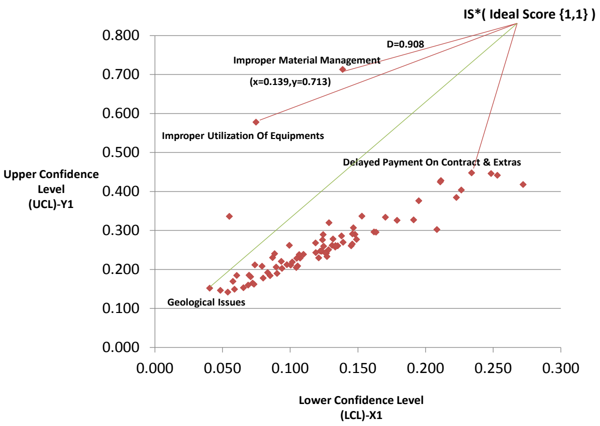

Fig.3 Severity Map-Distance Technique

Genetic Algorithm

A genetic algorithm is an optimization procedure that operates on sets of design variables. Each set is called a string and it defines a potential. Each string consists of a series of characters representing the values of the discrete design variables for a particular solution. The fitness of each string is a measurement of the performance of the design variables as defined by the objective function and the constraints.

Considering the data collected for piling activity, it has been observed that for each sub activity associated with piling work, there is a critical resource which has major impact on productivity in terms of cost and time.

"Evolver" is Excel software based on genetic algorithm which is widely used for optimization.

For such optimization, formulation of chromosome and other genetic terms are as follows:

Chromosome (string) : set of critical resources

Solution (coding) : optimum time & cost

Genes (bits) : variables-critical resources

Allele- Value of gene : no. of resources used

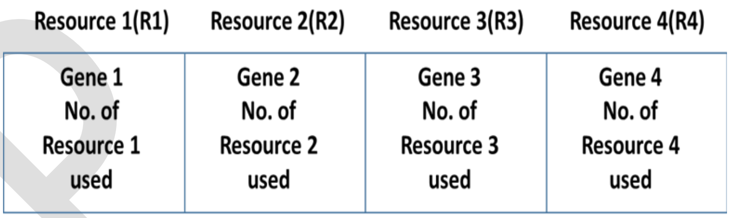

Fig. 4 Chromosome representation in form of resources

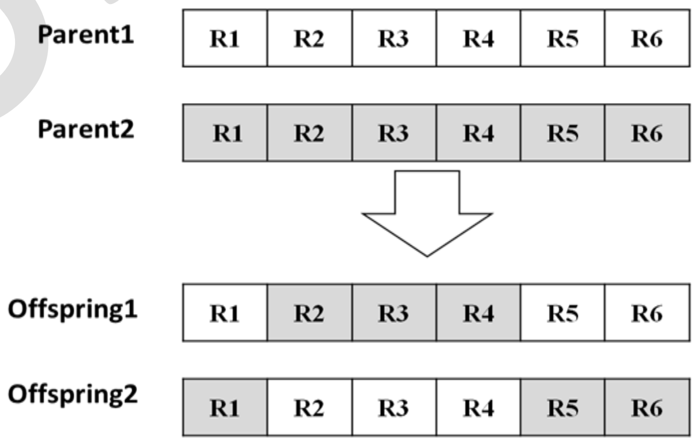

Fig. 5 Crossover operation to generate off-springs

Optimization Model

Considering the data collected for piling activity, it has been observed that for each sub activity associated with piling work, there is critical resource which has major impact on productivity in terms of cost (major equipments & manpower cost only) and time. The lists of major resources required for piling activity are presented in table 5.

Table 5: List of major resources required for piling activity

Resource Code	Resource	Sub-Activity
R1	Hydraulic excavator Ex200	Cleaning & shifting of utility services
R2	Surveyors team	Setting out & positioning tripod
R3	Soil auger	Soil boring
R4	Rock auger	Chiseling
R5	Reinforcement fitter	Cage formation & lowering
R6	Transit mixer	Concreting

Optimization modeling

Variables:

Above predefined six critical resources are considered to represent the resource quantities used in the piling work for optimization. Changing these values produces different results for total cost (major equipments & manpower cost only) and total time for desired productivity.

Constraints:

Following constraints are used in this model,

(i) Hydraulic excavator : INR 1100 / hr & an integer between 1 and 2
(ii) Surveyors : INR 400 / day & an integer between 1 and 2
(iii) Hydraulic Rig : INR .2200 / hr & an integer between 1 and 2
(iv) Skilled labors (chiesling) : INR 350 / day an integer between 2 and 4
(v) Reinforcement fitters : INR 400 / day & an integer between 3 and 4
(vi) Skilled labors (concreting) : INR 350 / day & an integer between 4 and 6
(vii) Working time: normal work-10hours / day and
(viii) Desired production: 60 piles (total number of piles in 12 piers)

Objective Function:

Optimize cost (major equipments & manpower cost only) and time considering the desired work productivity of 60 piles.

Optimization through Evolver

Evolver software is MS Excel add on tool. Process of optimization can be carried out through this software by first setting out the constraints, resources deployed and then finalizing the number of trials. Figure 6 shows the screen shot of evolver optimization setting.

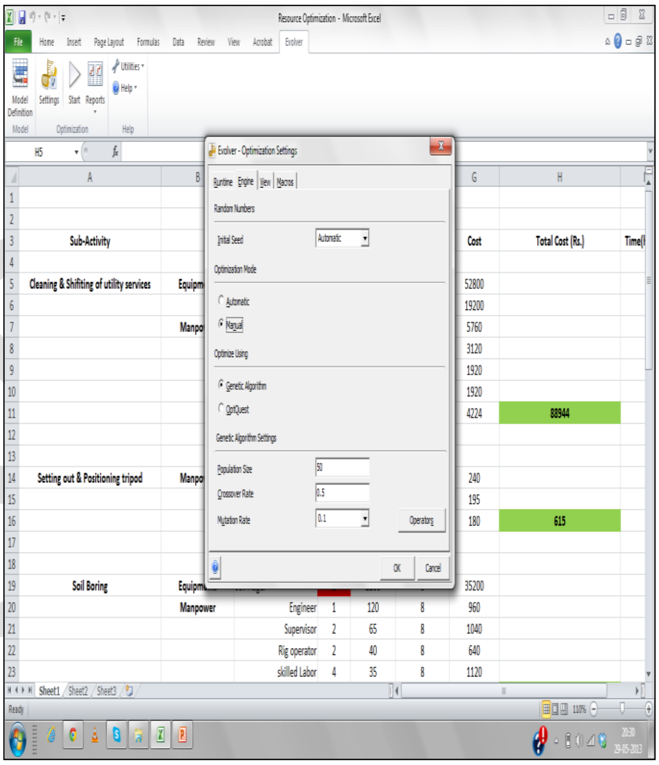

Fig. 6. Evolver optimization setting

Optimization Result

Table 6 shows the results of 50 trials resulted from evolver software for optimizing the cost and time of a typical pile.

Table 6: Optimization results of 50 trials resulted from evolver software

Trial	Resources						Cost per Pile	Time
No.	R1	R2	R3	R4	R5	R6	(INR.)*	(Hours)
1	**1**	**1**	**1**	**1**	**4**	**3**	**70673**	**547**
2	1	1	1	1	5	3	68941	546
3	1	1	1	2	4	3	70298	547
4	1	1	2	1	4	3	70193	488
5	1	1	1	1	3	3	72271	548
6	1	1	1	2	4	2	69728	608
7	2	1	1	1	4	3	72393	531
8	2	1	2	2	4	3	71538	472
9	1	2	1	1	4	3	70714	546
10	1	1	1	1	4	2	70103	608
11	1	1	1	1	4	4	68443	545
12	2	1	1	1	4	2	71823	592
13	1	2	1	2	4	3	70339	546
14	2	2	1	2	4	3	72059	530
15	1	1	1	1	5	4	66711	544
16	1	2	1	2	4	2	69769	607
17	1	1	2	1	3	3	71791	489
18	1	1	1	2	5	3	68566	546
19	1	2	1	1	4	4	68484	544
20	1	1	1	1	3	3	72271	548
21	1	2	1	1	5	3	68982	545
22	2	1	2	1	4	3	71913	472
23	2	1	1	1	5	3	70661	530
24	**2**	**1**	**2**	**1**	**4**	**4**	**68963**	**427**
25	1	1	2	1	5	3	68461	487
26	1	1	2	2	5	3	68086	487
27	1	2	1	1	4	2	70144	607
28	1	2	1	1	3	3	72312	547
29	2	2	1	2	3	2	73087	592
30	2	2	1	1	3	3	74032	531
31	1	1	1	1	4	2	70103	608
32	2	1	1	2	4	2	71448	592
33	1	2	1	2	5	3	68607	545
34	2	1	1	1	3	2	73421	593
35	2	1	1	1	3	3	73991	532
36	1	2	1	2	5	4	66377	543
37	1	1	1	2	3	3	71896	548
38	2	2	1	1	4	3	72434	530
39	2	1	1	2	4	3	72018	531
40	1	1	1	1	3	4	70041	546
41	1	2	2	1	3	4	69602	459
42	1	1	2	2	3	2	70846	609
43	1	2	1	1	5	4	66752	543
44	2	2	1	1	4	4	70204	528
45	1	1	1	2	3	4	69666	546
46	2	2	2	1	4	3	71954	471
47	1	2	1	2	3	3	71937	547
48	1	2	2	1	5	4	69004	446
49	1	2	2	1	4	3	70234	487
50	1	1	2	2	4	3	69818	488

*(*Note : Cost related to use of major equipments & manpower deployed for a typical pile is considered)*

CONCLUSIONS

For the bridge project under study, it is observed that the severe control variables affecting the resources management in chronological order are (i) improper materials management (ii) delayed payment on contract and extra items (iii) change in scope / extra items (iv) approvals from concerned authorities and (v) improper utilization of equipments. Using bootstrap technique, computation through equation 2 would result in finding the distance between ideal score (IS^*) and IS_j. Lesser the distance, more severe is the control variable. It has been observed that, improper materials management (M1) had minimum distance and hence is considered to be the most severe control variable. For piling activity for the bridge project under study for the desired production of 60 piles, the optimized number of resources are hydraulic excavators (2 nos.), hydraulic rotary rig (2 nos.), reinforcement fitters (4 nos.), transit mixers (4 nos.) against the actual number of resources used like hydraulic excavator (1 no.), hydraulic rotary rig (1 no.), reinforcement fitters (3 nos.), transit mixers (3 nos.). After optimization through evolver software, it has been observed that the cost for the major equipments and manpower deployed for each pile can be reduced by about

2.41% and the time savings can be to the tune of about 120 hours. But the proposed approach is best suited for the milestone activities of the project like piling activity, pier construction, girder construction and bridge deck construction. Also, evolver software has limitation like it can optimize one objective at a time. Thus, this optimization tool needs to be run twice to achieve the desired objective functions of optimizing the cost and time of the activities associated with the construction of the bridge project. Further, as the concept is generic, the proposed model can be applied for resource optimization and management for other infrastructure projects.

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