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Genetic Algorithm Based Optimization Model for Time-Cost Trade-Off for Construction Project

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Abstract: The main cause of gradual development of project management is the necessity of controlling and optimizing the construction project's objectives. In planning phase of construction project management, some objectives of proposed project are required to be set as per stakeholder's perspective. Time and cost are of paramount importance objectives of construction project, which vary due to variation in the resource utilization amount. High-cost resources and advance technologies reduce the project time but make the project cost higher. While low-cost resources and traditional technologies give lower project cost but increase the project time. Basically, a construction project is said to be successful if it is completed in minimum possible time and cost. Therefore, the two fundamental goals of any building project are to do it as quickly and inexpensively as possible. The development of time-cost trade-off models has received a lot of focus. However, in addition to a wide range of approaches for time-cost trade-off (TCT) models, this work offers a TCT model based on a genetic algorithm. This model was created in a way that makes it easier to find the best approaches to complete the project on time and for the lowest possible cost. The applicability of proposed TCT model is demonstrated through solving two practically existing construction project. Outcomes of proposed model were found satisfactory based on statistical analysis.
Keywords: construction project, time-cost trade off, genetic algorithm, project management.

I. INTRODUCTION

The problem of time-cost trade-off is a major issue in construction projects, it is required to solve it before starting the construction project. Project managers often encounter several issues in solving the TCT problem such as variation in resource utilization amount and constraint period and overall cost of project. Time and cost are of paramount importance objectives in the construction project management. Time and cost of project are not independent but intricately related objectives. Mostly, when the construction time of project is decreased, all the entities like labour requirement, productive equipment, procurement and construction management will increase and then finally the outcome will hike project cost. TCT optimization is a process to identify best possible combination for both time and cost. Since there is a concealed agreement between project time and cost, so it is difficult to predict the effect of reducing time on overall cost of the project whether it will increase or decrease it. As different combinations of possible project duration and cost exist to execute the project, still it is required to select best possible combination of time and cost of project. Determination of this best possible combination of time and cost of project is the main goal of applying optimization algorithm in solving the TCT problems.

In a market where there is intense competition, it is crucial to cut project costs and duration. However, a compromise between project time and expense is necessary. This calls for contracting companies to thoroughly assess alternative methods in order to achieve the best time-cost equilibrium. Although several analytical models for time-cost optimization (TCO) have been created, they primarily concentrate on projects where the contract term is fixed. In those circumstances, the optimization goal is limited to finding the lowest total cost. Clients and contractors are focusing on the enhanced benefits and prospects of obtaining an earlier project completion as alternative project delivery systems gain popularity. The multi-objective TCO model that is presented in this paper is powered by genetic algorithmic approaches.

Researchers learned about a new methodology for the arrangement of time–cost exchange off issues a dubious situation. Fluffy numbers are utilized to manage the vulnerabilities inside the development's execution examples and project cost. Fuzzy units hypothesis is tuned and phenomenally inserted within the advancement process. A multi- objective hereditary calculation is exceptionally hand crafted to fathom the unpredictable and multi-objective fluffy time and cost model with moderately bigger hunt phase. The arranged methodology recognizes the best arrangement of use choices characterized by the arrangements of non-ruled arrangements. Fluffy assessments of the potential results of the outcomes to distinguish the non-ruled arrangements help to represent whole scopes of conceivable time and cost varieties. The focused-on strategy expressly considers the hazard acknowledgment level and the confirmation of the venture director in an official choice.

Researchers have also analysed the affiliation among time and price, set up time- cost optimization fashions of creation projects and received the circumstance of optimizing duration. This study reflects the relation among time and cost, they also developed models for construction project having time-cost merger and found the ways or situations for optimizing project duration. It provides base for decision making on scientific models and it helps to take decision powerfully. The result shows that the models are convenient, effective and efficient. This proposed model was found capable in assisting project manager in taking various decision-making situations. Authors also demonstrated the working of proposed model.

Holland (1975) created the genetic algorithm (GA), a population-based method that draws inspiration from nature and is used to look for solutions to optimization issues. In the GA process, the parent population, which consists of the first N solutions to the optimization problem generated at random in encoded chromosomal form (Pt). Pt passes through selection, crossover, and mutation operations after having its fitness value evaluated in order to produce an offspring population (Ot). Based on the fitness values of the offspring population, optimal solutions are then recorded. The Multi-Objective Genetic Approach was a new multi-objective optimization algorithm that Srinivas and Deb (1994) proposed after extending the GA (MOGA). To produce non-dominated front of solutions in MOGA, offspring population goes through non-dominated sorting. First non-dominated front is regarded as Pareto-optimal front in minimization problems since it comprises Pareto-optimal solutions.

II. RESEARCH OBJECTIVES

The detailed research objectives are as follows:

1) Investigate the performance of several deterministic (mathematical), heuristics and meta-heuristics optimization methods through literature review.
2) Development of a time-cost trade-off MATLAB programme using genetic algorithm optimization method.
3) Validation of developed time-cost trade-off model by applying it on a real case study project.
4) To supports the efforts of construction firms for optimizing time and cost of their real-world construction projects.

III. TOOL AND TECHNIQUES

1) Multi-objective genetic algorithm (MOGA).
2) MATLAB and MS Excel.

IV. RESEARCH METHODOLOGY

Time and cost are of paramount importance and intricately related objectives of any construction project. It is commonly recognized that project require more labour, more productive equipment, modern resources and technologies when the project duration is compressed. Therefore, project cost increases as the use of modern resources and technologies increase. The adopted two objective optimization problem is formulated as follows;

1) *Project Completion Time (PT):* PT is the time required to complete the project.

Objective 1: Minimize PT

$$\mathrm{PT} = \sum_{A \in CP} AT_A \quad \textbf{(1)}$$

Where, AT_A is completion time of an activity A.

2) *Project Cost (PC):* PC is the total capital required to compete the project.

Objective 2: Minimize PC

$$\mathrm{PC} = \sum_{A} D.C \ + \mathrm{I.C\ per\ day} \times \mathrm{PT\ in\ days} \quad \textbf{(2)}$$

Where, $\sum_A D.C$ is sum of direct cost of each activity.

The detailed procedure to complete the model is explained as follows;

a) Step-1) At first the initial population is generated randomly and ranked based on non-dominated sorting *(NDS)*, and crowding distance. A solution of first non-dominated front with highest value of crowding distance should be of rank one and solution of last non-dominated front with lowest value of crowding distance should be of rank N.
b) Step-2) Tournament selection is carried out to develop the mating pool.
c) Step-3) Simulated binary crossover is carried out using following formula;

$$C_1 = 0.5\,[(1 + \beta_i)\,P_1 + (1 - \beta_i)P_2] \quad (3)$$

$$C_2 = 0.5\,[(1 - \beta_i)\,P_1 + (1 + \beta_i)\,P_2] \quad (4)$$

While β_i is calculated as follow:

$$\beta_i = \begin{cases} (2u_i)^{1/(n_c+1)}, & if\ u_i < 0.5 \\ [1/2(1 - u_i)]^{1/(n_c+1)}, & otherwise \end{cases} \quad (5)$$

Where, u_i lie in range [0,1] and n_c is a crossover constant.

a) Step-4) Mutation is carried out using following formula;

$$C = P + (x_i^{(u)} - x_i^{(l)})\,\delta_i \quad (6)$$

δ_i is calculated as follows;

$$\delta_i = \begin{cases} (2r_i)^{1/(n_m+1)} - 1, & if\ r_i < 0.5 \\ 1 - [2(1 - r_i)]^{1/(n_m+1)}, & if\ r_i \geq 0.5 \end{cases} \quad (7)$$

Where, r_i lie in the range [0,1] and n_m is mutation constant.

b) Step-5) Non-dominated sorting is carried out to create the Pareto-optimal front.

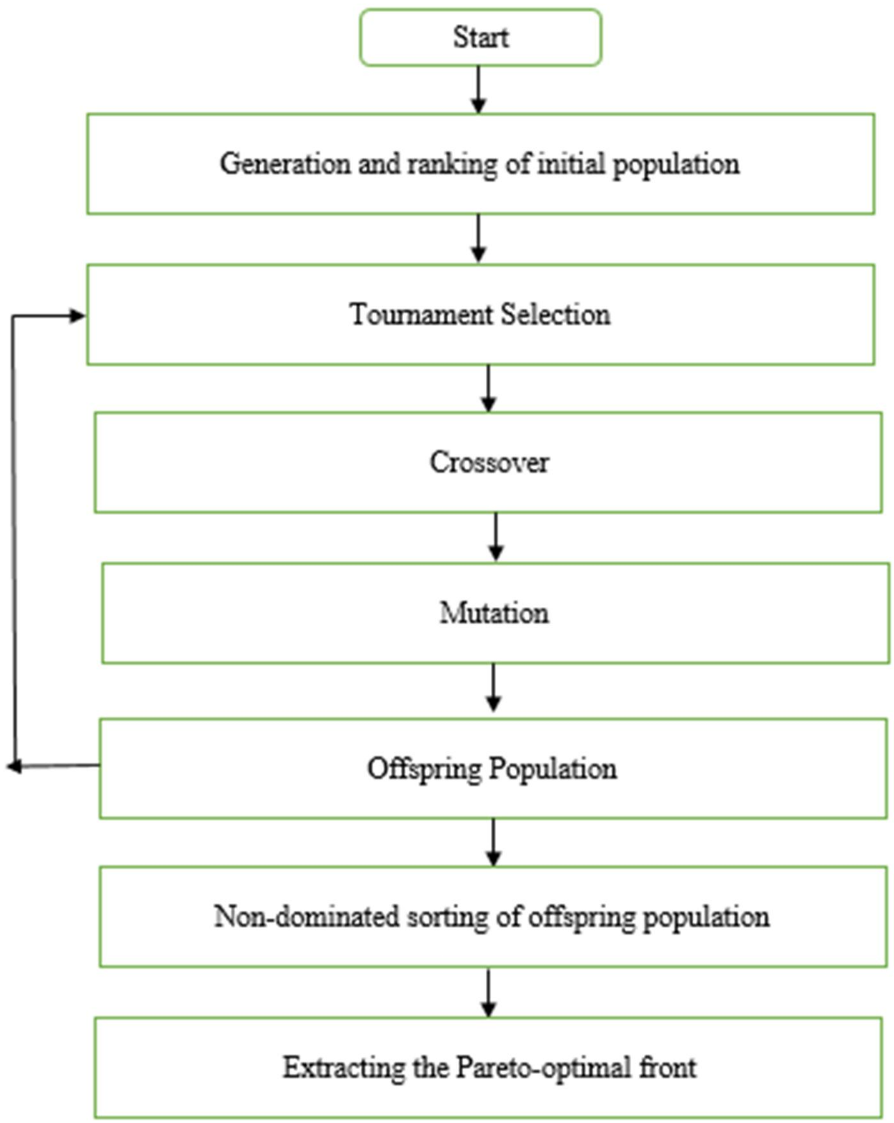

Figure 1 One generation of MOGA

V. CASE STUDY PROJECT

To demonstrate the working of proposed genetic algorithm-based time-cost trade-off model, it is practically implemented on two real case study projects as explain below:

A. *Case Study-1*

Details of first case study project is given below in Table 1. This case study is taken from a previous study of Panwar & Jha (2019). This project consisted of 11 activities. Activities were had maximum four alternate options to execute. Each alternate option was associated to different values of time and cost based on the type of resource. The project network diagram for this project is portrayed in Figure 2.

Table 1. Details of case study of project (Panwar & Jha, 2019)

ID	Activity	Successors	Alternate Options	Time (Days)	Cost (US $)
1	Site Work	2	1	4	5039.71
			2	4	4924.93
2	Excavation	3	1	2	360.71
			2	2	297.05
3	Footing	4	1	6	84232.67
			2	5	90392.28
4	Stem wall	5	1	13	76650.79
			2	8	86174.94
5	Slab	6	1	11	14636.05
			2	7	16758.59
6	Exterior wall	7	1	6	25959.52
			2	14	65399.94
			3	5	127542.42
7	Interior wall	11	1	18	27970.53
			2	10	35650.22
			3	15	27508.21
			4	8	34365.99
8	Flooring	D	1	16	28341.60
			2	12	45616.48
			3	8	36554.88
9	Exterior Finish	D	1	31	69659.78
			2	23	233034.50
10	Interior Finish	D	1	3	4006.80
			2	4	1746.55
11	Roof	8,9,10	1	21	117851.84
			2	23	69253.17

As shown in Table 1, the first activity is site work in which the equipment and materials are moved towards the working site and site is prepared for construction.
In the second activity is excavation, which is carried to lay foundation.
Third activity is footing, which is the part of sub-structure.
Fourth activity is stem well.
Fifth activity is slab construction.
Sixth and seventh activities are exterior and interior wall construction.
Eighth activity is flooring.
Ninth and tenth activities are exterior and interior finish activities.
Eleventh activity is roof construction activity.
Twelfth activity is dummy activity.

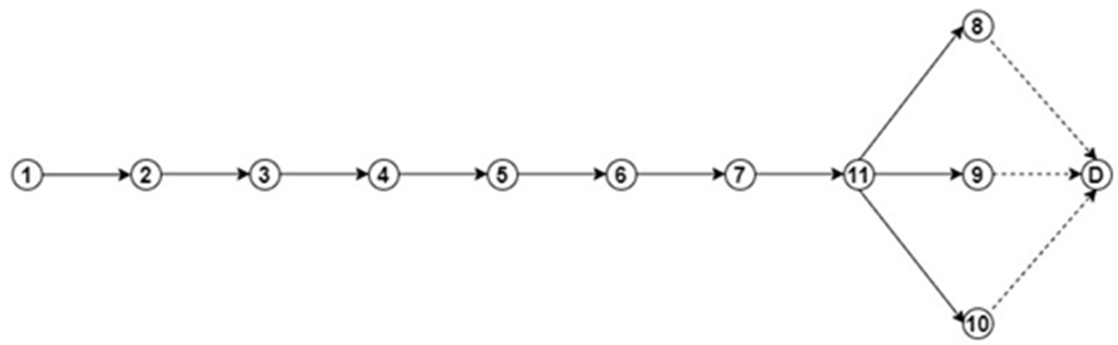

Figure 2 Project Network Diagram for First Case Study Project

The best possible combination of MOGA parameters were adopted and shown in Table 2.

Table 2 Adopted values of MOGA parameters

MOGA Parameters	Value
Population Size	100
Number of Generation	150
Crossover Probability	1
Crossover distribution index	20
Mutation probability	1
Mutation rate	1/13
Mutation distribution index	20

Total 9 exclusive optimal combinations of activity alternate options were obtained, in which PT values varies from 90 to 106 days, and PC values varies from 411556.10 to 648946.40. All these solutions are presented in Table 3.

Table 3 Obtained Pareto-Optimal Solutions for 1st case study project

Sr. No.	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	PT (In Days)	PC (In US $)
1	2	1	2	2	1	1	4	3	2	1	2	90	599663.8
2	2	1	2	1	2	1	2	2	2	2	1	91	648946.4
3	1	1	1	2	2	1	2	2	1	2	2	97	440452.3
4	1	2	2	1	2	3	2	2	1	1	1	98	589466.0
5	2	1	2	2	2	3	3	1	1	2	2	100	522663.2
6	2	1	1	2	1	1	1	3	2	2	2	101	584848.4
7	1	2	1	2	2	2	2	1	1	1	1	103	513413.1
8	1	1	2	2	1	1	3	2	1	1	2	105	438607.6
9	2	1	2	1	2	1	3	1	1	2	2	106	411556.1

Based on time-cost values obtained in Table 3, time-cost trade-off curve is plotted as Figure 3.

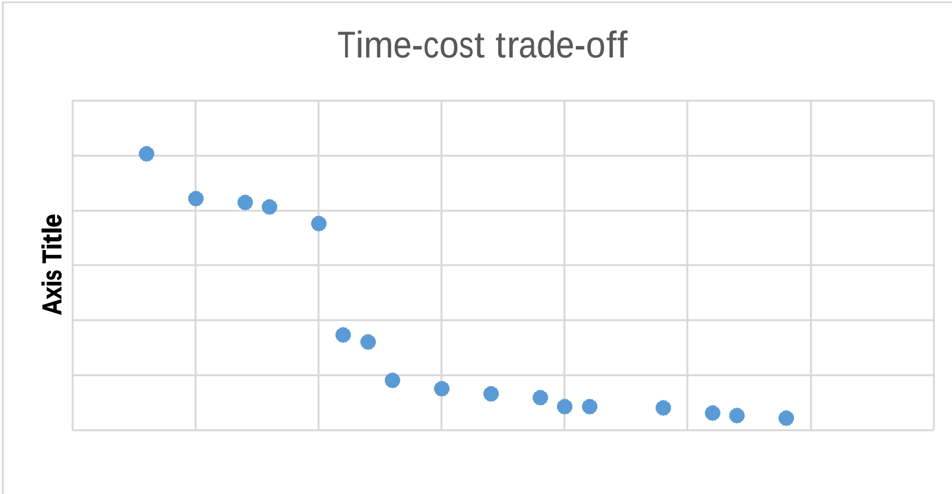

Figure 3 Time-cost trade-off curve for 1st case study

B. Case Study-2

Second case study project is developed based on the data available in literature and shown in Table 4. This project consisted of 13 activities. Activities were had maximum four alternate options to execute. Each alternate option was associated to different values of time and cost based on the type of resource. The project network diagram for this project is portrayed in Figure 4.

Table 4. Details of the case study project

Sr. No.	Activity Name	Successors	Alternatives	Time (days)	Cost (INR)
1	Site Preparation	2, 3	1	10	200788
			2	9	196997
2	Excavation of Foundation	4	1	7	71643
			2	7	77821
3	Casting of Footing	4	1	13	310913
			2	11	340780
4	Plinth Construction	5	1	6	110243
			2	5	118006
5	Cast of Columns	6	1	27	316680
			2	17	345480
6	Slab	7, 8	1	23	482493
			2	12	526916
7	Stairs	9	1	33	686247
			2	30	652921
			3	24	595192
8	Exterior wall	9	1	19	1319190
			2	30	2105939
			3	12	3148668
9	Interior wall	13	1	38	1171407
			2	22	1199988
			3	33	1153366
			4	18	1266422
10	Flooring Works	14	1	35	968230
			2	18	1306530
			3	13	1004284
11	Exterior finish	14	1	10	44325

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			2	13	76925
12	Interior finish	14	1	42	1804396
			2	32	4660690
13	Roofing Works	10,11,12	1	24	2552837
			2	25	1626463
14	Dummy Activity	-	-	-	-

As shown in Table 4, the first activity is site preparation in which the equipment and materials are moved towards the working site and site is prepared for construction.
In the second activity is excavation of foundation, which is carried to lay foundation.
Third activity is footing, which is the part of sub-structure.
Fourth activity is plinth construction to provide plane surface to the construction work.
Fifth activity is casting of columns.
Fifth activity is slab construction.
Seventh activity is stairs construction.
Eighth and ninth activities are exterior and interior wall construction.
Tenth activity is floor construction.
Eleventh and twelfth activities are exterior and interior finish activities.
Thirteenth activity is roof construction activity.
Fourteenth activity is dummy activity.

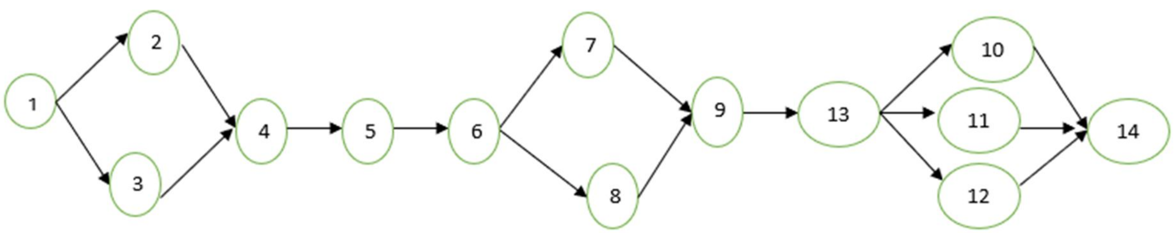

Fig. 3 Project Network Diagram for Second Case Study Project

Total 10 unique optimal combinations of activity alternate options were, in which PT values varies from 178 to 223 days, and PC values varies from 9129954 INR to 14312019. At minimum PT, the maximum value of PC is found. All 9 obtained Pareto-optimal solutions are presented in Table 5.

Table 5 Obtained Pareto-Optimal Solutions for 2nd case study project

Sr. No.	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	PT	PC (in INR)
1	2	2	2	2	2	2	2	3	4	2	1	2	1	178	14312019
2	2	2	2	1	2	2	2	1	4	3	2	2	1	185	13131506
3	2	1	1	1	2	2	3	1	2	2	1	2	1	186	12314570
4	1	1	2	1	2	2	3	3	3	2	1	1	2	180	13557458
5	1	1	2	2	2	1	3	1	2	1	1	1	2	195	11599642
6	1	2	2	2	1	2	1	3	4	1	2	2	1	202	11158342
7	2	1	1	2	2	2	1	1	2	2	2	2	1	204	9589694
8	2	2	1	1	1	2	3	1	2	1	2	2	1	206	9129954
0	1	1	2	1	2	2	1	1	2	2	2	2	2	203	10541963
10	2	2	2	2	1	2	1	1	3	3	2	2	1	223	9248071

Based on time-cost values obtained in Table 5, time-cost trade-off curve is plotted as Figure 5.

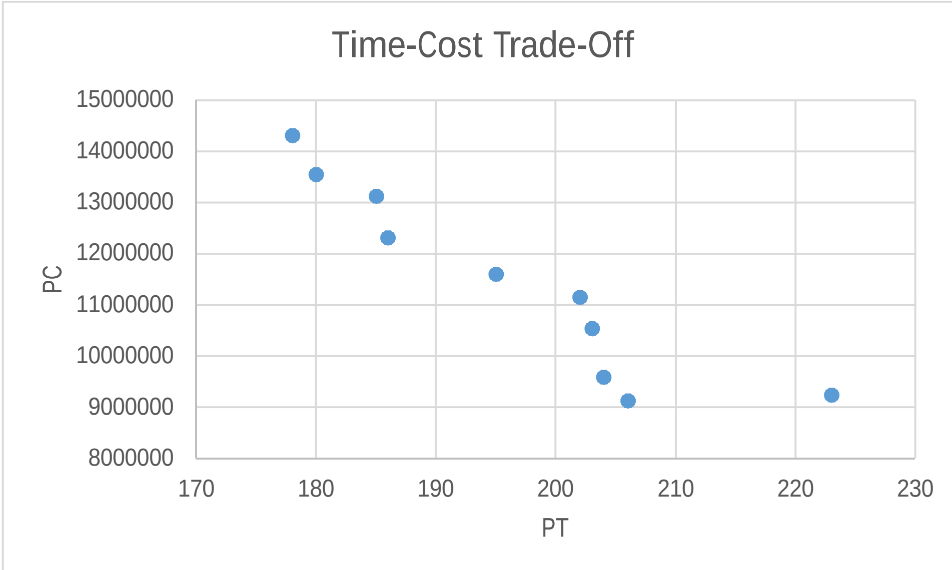

Figure 5 Time-cost trade-off curve for 2nd case study

Project planning is a channel between the experiences of the past projects and the proposed actions that produces constructive results in the future. It can also be said that it's far a precaution by which we can lessen unwanted consequences or unexpected happenings and thereby eliminating confusion, waste, and loss of performance. Planning includes previous resolve specification of things, forces, effects and relationships vital to attain the preferential object. In planning phase, some objectives of such as time and cost are required to be set as stakeholder’s perspective. In scheduling, a compressed schedule of project with optimum cost is required to be made with fulfilling the project objective set in planning phase. In project controlling, project schedule is to be revised if there is any disturbance in main timetable of project schedule.

Description of alternatives of project’s activities are given below in Table 6;

Table 6. Description of each alternate option of each activity

ID	Activity	Successors	Alt	Description of Alternative
1	Site Preparation	2, 3	1	Site clearance, site preparation for construction and finish grading
			2	Site clearance, site preparation for construction, finish grading and groundwater control
2	Excavation of Foundation	4	1	6 to 8 feet deep, JCB JS140 crawler excavator and backfill trench
			2	6 to 8 feet deep, JCB JS120 crawler excavator and backfill trench
3	Casting of Footing	4	1	M25 Concrete, TMT bars and direct chute
			2	M25 Concrete, TMT bars, pumped and MIVAN formwork
4	Plinth Construction	5	1	Steel formwork
			2	MIVAN formwork
5	Cast of Columns	6	1	M25 Concrete, TMT bars and direct chute
			2	M25 Concrete, TMT bars, pumped and MIVAN formwork

6	Slab	7, 8	1	M25 Concrete, TMT bars and steel formwork
			2	M25 Concrete, TMT bars, MIVAN formwork
	Stairs	9	1	M25 Concrete, TMT bars, pumped and MIVAN formwork
7			2	M25 Concrete, TMT bars and direct chute
			3	M25 Concrete, TMT bars, pumped and MIVAN formwork
8	Exterior wall	9	1	First class brick and standard mortar
			2	First class brick, standard mortar and EPS insulation
			3	Hollow block, standard mortar and XPS insulation
9	Interior wall	13	1	First class brick, standard mortar and XPS insulation
			2	First class brick, standard mortar and XPS insulation
			3	First class brick and standard mortar
			4	Hollow block, standard mortar and XPS insulation
10	Flooring Works	14	1	Wood, bamboo strips, finished
			2	Prefinished white oak, prime grade and crew doubled
			3	Ceramic tile, floors, glazed and crew doubled
11	Exterior finish	14	1	18 mm thick plaster of standard mortar, XPS insulation, double coat plastic paint
			2	12 mm thick plaster of standard mortar, EPS insulation, single coat plastic paint
12	Interior finish	14	1	12 mm thick plaster of standard mortar, EPS insulation, single coat plastic paint
			2	18 mm thick plaster of standard mortar, XPS insulation, double plastic paint
13	Roofing Works	10,11,12	1	Standard thickness, M25 concrete, TMT bars, admixtures, EPS insulation and MIVAN formwork
			2	Standard thickness, M25 concrete, Fe 415 bars, steel formwork

VI. CONCLUSION

Number of ways to deliver the project increase as the number of activities and their number of alternate options increases in project. Besides, time and cost are the most focused objectives of project planning and success. However, decreasing the project cost delay the project. Therefore, there is a trade-off between time and cost of project.

Numerous studies have been done recently to optimize project time and cost in resource-constrained conditions. Due to the fact that most research treat time and cost as continuous variables, resources are available in discrete amount and time and cost are different to each set of resources for different activities. Several trade-off methods exist in literature such as mathematical methods, heuristics methods and meta-heuristics. Meta-heuristics methods have shown effectiveness in solving large scale optimization problem. Hence, a meta-heuristic method the genetic algorithm is used in this research to solve the time-cost trade-off problem.

Therefore, this study provides the multi-objective genetic algorithm (MOGA) based optimization model for time-cost trade-off for construction project. By completing two case study projects involving the construction of buildings, the proposed model's effectiveness is shown. The case study project's findings highlight the following abilities of the suggested model. First, because time and cost can affect one another, it's crucial to optimize both of them simultaneously when resources are limited. Second, MOGA is determined to be effective in resolving multi-objective optimization issues. Third, it has been discovered that the suggested model is effective in producing satisfactory and high-quality Pareto-optimal solutions. Finally, this study maybe offers a reliable tool for construction organizations to use when making worthwhile project scheduling decisions.

Besides, proposed model assists project team in taking time and cost-efficient decisions regarding the project. Project manager can also select one solution based on preference in context of construction project. Furthermore, proposed study provides some recommendations to assist the client, contractor and consultant of project in various decision-making situations.

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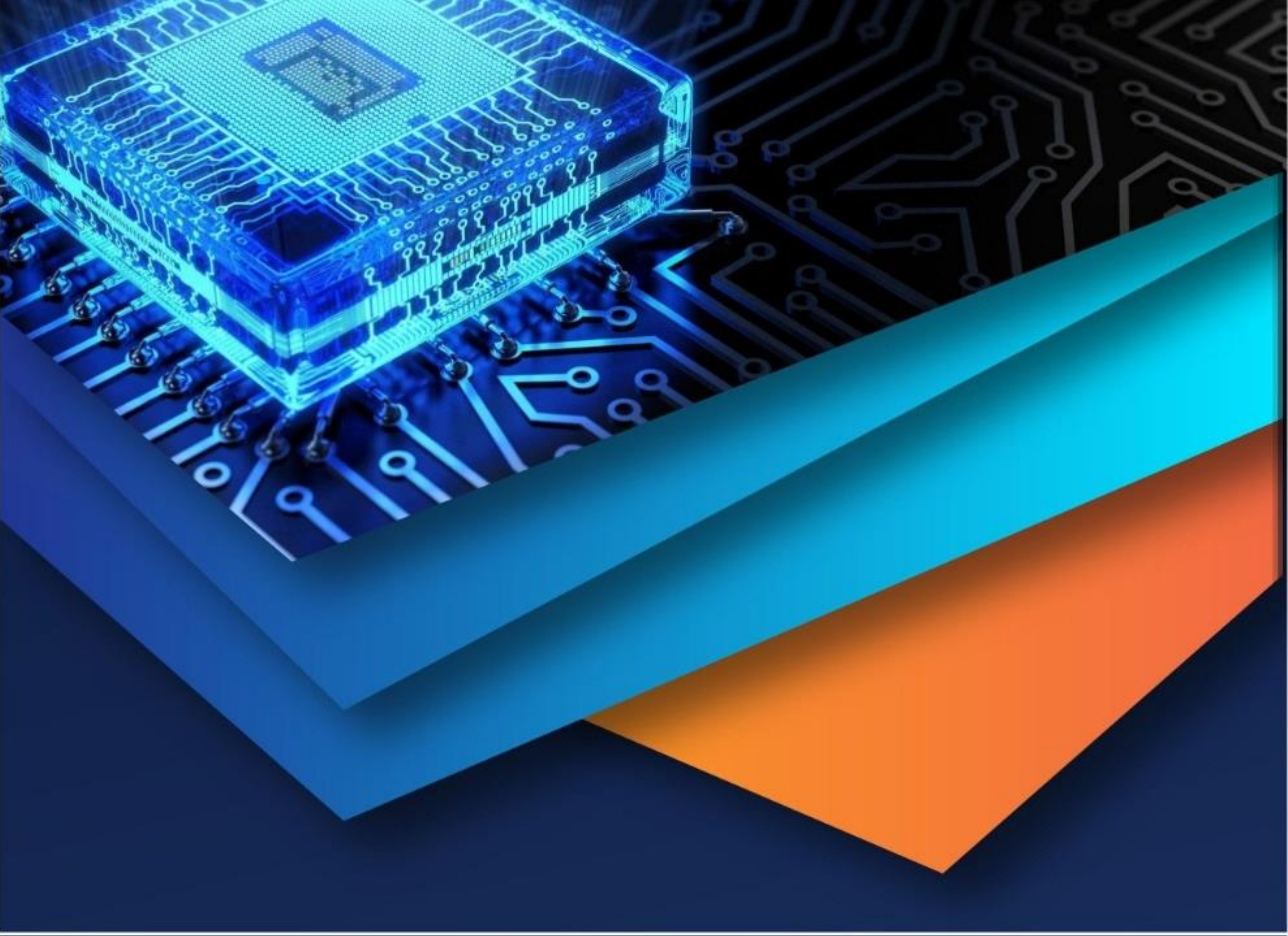

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IMPACT FACTOR: 7.129

TOGETHER WE REACH THE GOAL

IMPACT FACTOR: 7.429

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