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Fuzzy Multi-Objective Genetic Algorithm Based Resource Constrained Time-Cost Trade-Off Model under Uncertain Environment

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Abstract: In every construction project, the time and cost are the two most important objectives/factors to be considered. Clients and contractors should strive to optimize the project time and cost to maximize the return. Resources are also one of the major constraints of the construction projects. In recent years, several studies have been conducted to optimize the time and cost of project under constraint conditions of resources. Since most studies assume the time and cost as deterministic parameters, uncertainties should be considered in estimating the time and cost of the project's activities when minimizing the duration and cost of the project. For this purpose, this paper embeds the fuzzy logic to handle the uncertainties in estimating the time and cost. Besides, the multi-objective genetic algorithm (MOGA) is used to develop the resource constrained time-cost trade-off model. Alpha-cut approach is utilized to define the accepted risk level of decision maker. The efficiency of the proposed model is demonstrated through solving a case study project of highway construction. The results of case study project provide a set of Pareto-optimal solutions. The developed model encourage the decision making process by choosing specified risk levels and utilizing the related Pareto-front.
Keywords: Construction projects, time-cost trade-off, uncertainties, fuzzy logic, MOGA, Pareto-optimal solution.

I. INTRODUCTION

Time and cost are the most important objectives of the real life construction projects. In a construction project, there are two main important parameters i.e. the project duration and theproject cost. While the resources are the third most important aspect which are very much needed in the construction. Today's competitive construction market requires to complete the project within minimum time and cost under constraint limit of resources. Time-cost trade-off has been a longer known problem and several researchers have paid significant amount of consideration to develop various time-cost trade-off models in different scenarios.

In the previous years, also, a significant amount of attention has been paid to complete the project within the minimum time and cost so that clients and contractors can maximize their return. To date, no sign of decelerating momentum is found in further optimizing the time and cost of construction projects. Habibi *et al. (2013)* explained four types of resource constrained time-cost trade-off models. Of which, activities alternative concept is utilized in the presented study. A construction project comprises of a number of interconnected activities (Singh and Ernst 2011). Individual activity can be executed by one of its several available alternatives. Each alternative is accompanied by varying amounts of resources, execution time and completion cost. Numerous completing ways for a project are possible based on the possible combinations of activities alternatives. Therefore, project manager is required to select the optimal combinations of activities alternatives while minimizing the time and cost of project. Since the time and cost are the two most important and contradictory objectives of construction project planning and success (Zahraie and Tavakolan 2009), it is well known fact that the time-cost trade off (TCT) problems are required to reduce the duration of activities by using modern expensive resources. However, modern expensive resources increase the cost of project.Therefore, there exists a hidden trade-off between the time and cost of project. In the last few decades, a significant amount has been given to develop the resource constrained time-cost trade-off models (Feng *et al.* (1997), Zheng *et al.* (2004), Tiwari and Johari 2015). Most of the resource constrained TCT studies are based on the assumption that the time and cost of an alternative within an activity are deterministic. However, in fact they are uncertain. The time and cost values for an alternative can be between the minimum possible and the maximum available value range. Therefore, the uncertainties should be considered in estimatingthe time and cost of the project's activities when minimizing the duration and cost of the project.For this purpose, this study embeds the fuzzy logic to handle the uncertainties in estimating thetime and cost. Besides, the multi-objective genetic algorithm (MOGA) is used to develop the resource constrained time-cost trade-off model. Alpha-cut approach is utilized to define the accepted risk level of decision maker. The efficiency of the proposed model is demonstrated through solving a case study project of highway construction and comparing it with an existing model. The results of case study project provide a set of Pareto-optimal solutions. Thedeveloped model also encourage the decision making process by choosing specified risk levelsand utilizing the related Pareto-front.

II. RESEARCH OBJECTIVES

1) *Main Objective:* The main objective of this research is to find the optimum way or ways to deliver the project successfully under consideration of time-cost trade-off optimization under the uncertain environment and constraint limit condition.
2) *Sub Objective:* With the main objective, this research also targets following sub-objectives:

a) To understand the uncertain time and cost management under resource constrainedconditions in construction.
b) Extensive literature survey of Fuzzy resource constrained time-cost trade-offoptimization in construction project.
c) To study the multi-objective optimization techniques.
d) Handling the uncertainties in resource constrained time-cost estimation of constructionactivities using fuzzy logic.
e) To develop a MATLB model for Fuzzy resource constrained time-cost trade-offoptimization. This model should be able to generate the quality Pareto-optimal front.
f) To demonstrate the proposed model through solving a real case study project.
g) To provide a priori approach to select one solution from obtained Pareto-optimal front.
h) To propose some recommendations for time and cost optimization in constructionproject.

III. TOOL AND TECHNIQUES

A. For handling the uncertainties fuzzy logic is used. Alpha-cut approach is used to encounterthe uncertainties.
B. For optimization process, multi-objective genetic algorithm (MOGA) is used.
C. Fuzzy logic and MOGA are described in detail in the literature review chapter.

IV. RESEARCH METHODOLOGY

In the presented study, for each activity, the uncertain activity time (t) and cost (c) are described as triangular fuzzy numbers using linguistic terms as follows: minimum, most likely and maximum.

Table: 1 Linguistic terms for time and cost

Linguistic terms for time	t_1	Minimum time
	t_2	Most likely time
	t_3	Maximum time
Linguistic terms for cost	c_1	Minimum cost
	c_2	Most likely cost
	c_3	Maximum cost

t2 is between t1 and t3, while c2 is between c1 and c3. The triangular fuzzy numbers for activity time and cost are shown in Fig. 1.

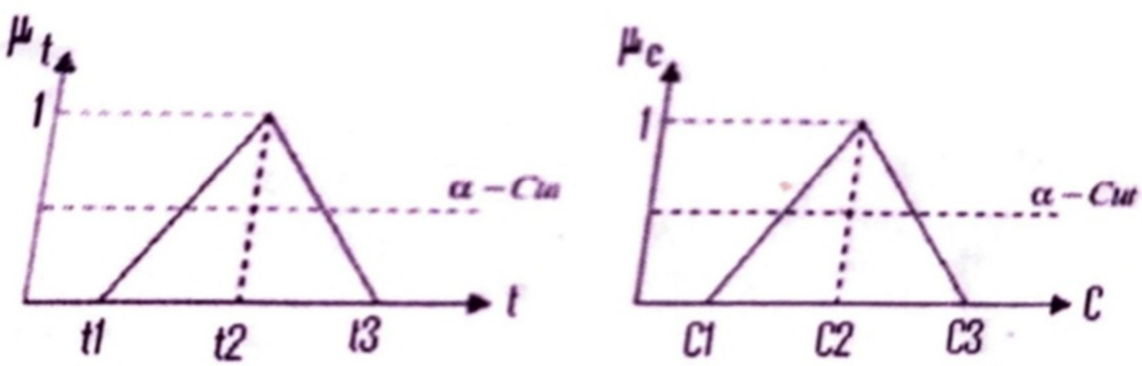

Fig. 1 Fuzzy membership function for activity time and cost

Where, Fuzzy ith activity time ti = (t1, t2, t3) $t1 \leq t2 \leq t3$
Moreover, Fuzzy ith activity cost ci = (c1, c2, c3) $c1 \leq c2 \leq c3$
In order to resolve the fuzzy numbers into crisp numbers, the fuzzy alpha-level cut approach is used. Then, the mathematical operations such as addition, multiplication and division can be performed on crisp numbers. The alpha-level cut (α-cut) of a fuzzy set

A can be given by:

Aα = {(x, uA (x)) ≥ α │x € X} ∀ X € [0, 1]}

At a α-cut value, different values of fuzzy cost and fuzzy time are converted to crisp values by using the centre of gravity defuzzification method, which is calculated as follows:

$$\textbf{Output} = \frac{\int \mu(x) x dx}{\int \mu(x) dx}$$

eq. 1

Once, the crisp outputs are generated, the crisp outputs then underdo the MOGA process to solve the presented TCT problem.
This simultaneous two objectives optimization problem can be defined as follows: (i) minimization of PT (ii) minimization of PC (iii). These two construction project objectives are formulated in following manner:

1) *Project Completion Time (PT):* PT is an important parameter of construction project which greatly influence the success of construction project. In this paper, precedence diagramming method (PDM) is employed to calculate PT. PDM is based on critical path (CP) of activity on node (AON) project networks. PT is the summation of AT of all the activities in the critical path of construction project.

Objective 1: Minimize PT

$$PT = \sum_{A \in CP} AT_A \qquad \textbf{eq. 2}$$

Where PT is project completion time, A is an activity on the critical path (CP) and AT_A is completion time of an activity A.

2) *Project Cost (PC):* PC is one of important factor affecting the success of construction projects. PC is simply the algebraic sum of each activity completion cost (AC). AC comprises of direct cost and indirect cost. Direct cost (D.C) include mainly the cost of labour, material and equipment while indirect cost include overhead expenses and outage losses.

Objective 2: Minimize PC

$$PC = \sum_A D.C + \text{I.C per day} \times \text{PT in days} \qquad \textbf{eq. 3}$$

Where PC is project completion cost, $\sum_A D.C$ is sum of direct cost of each activity. Indirect cost of construction project is simply estimated by multiplying the PT and indirect cost per day.

The key constraints considered in this study are as follows: (i) each activity should be completed for the successful completion of project (ii) only one out of available alternatives should be initiated to complete the activity. (iii) Alternatives of each activity which are the decision variables, must be positive integers and subject to lower and upper bound and (iv) Precedence relationships between activities should be maintained during optimization process.

Holland **(**1975**)** proposed genetic algorithm (GA) which is a population based nature inspired algorithm for solution searching and optimization problems. In process of GA, initially *N* solutions of optimization problem in encoded chromosome form are randomly generated which is known as parent population (P_t). After evaluating the fitness value of P_t, P_t then undergoes selection, crossover and mutation operation to generate offspring population (O_t). Optimal solutions are then recorded from offspring population based on fitness values of offspring population. Srinivas and Deb (1994) extended the GA and introduced a new multi-objective optimization algorithm i.e. Multi-Objective Genetic Algorithm (MOGA). In MOGA, offspring population undergoes non-dominated sorting to generate non-dominated front of solutions. In minimization problems, first non-dominated front is considered as Pareto-optimal front that contains Pareto-optimal solutions.

MOGA starts with generating the random population of size *N*. Detailed description of MOGA procedure to solve the TCT problem is explained as follows:

a) *Generation and ranking of initial population (P_t) of size N:* First of all, an initial population(parent population P_t) of size *N* (i.e. *N* chromosomes) is generated randomly. Ranking of population is done in this step.
b) *Selection (also known as reproduction stage):* In selection stage, ranked initial population undergoes tournament selection in which *N* pairs of ranked initial population are randomly selected. Then, a tournament is carried out between *N* pairs of solutions and the winner solutionis decided on the basis of ranking produced by NDS. Therefore, a mating pool of size *N* was obtained after tournament selection.

c) *Crossover:* In crossover operation, two randomly selected population members from mating pool undergo crossover operation.

d) *Mutation:* To keep diversity in population, a chromosome is mutated to another chromosome by a small random tweak in chromosome. Population generated from crossover operation undergo mutation operation to generate offspring population *(Ot)* or child population.

e) *Non-dominated Sorting of offspring population (Qt):* Generated offspring population *(Ot)* after SBX and PM undergoes non-dominated sorting to sort the solutions in non-dominated fronts *(F1, F2 …Fl.. Fn)*. The first non-dominated front *(F1)* is considered as Pareto-optimal front. After the termination condition of algorithm, the first non-dominated front of last generation is considered as solution of given problem. Since MOGA is iterative procedure, so the process is continue till the stopping criterion met. General stopping criteria are themaximum number of generation or the attained convergence of solutions, or both.

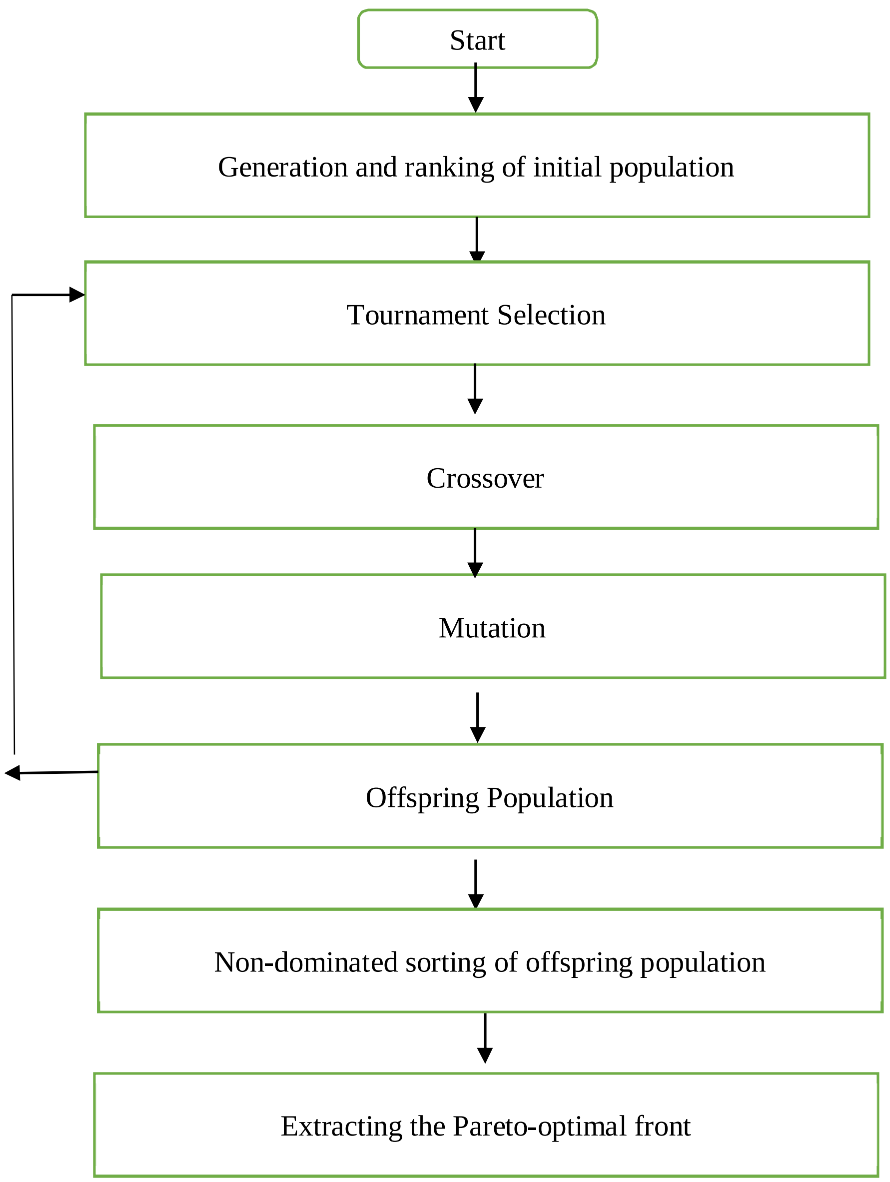

Fig. 2 One generation of MOGA

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V. CASE STUDY PROJECT

A following highway construction case study project was taken for applying the proposed model.

1) *Case Study Project:* A highway case study
2) *Name of Project:* 1 Km length of NH-34 (Near Kannauj)

This construction project was facing so many problems in selecting optimal combination of alternate options to deliver the project successfully. This project consisted of 13 activities. Name, successor, number of available alternatives of each activity and corresponding values of objectives (minimum, most likely and maximum time and cost) are given in Table 2. Duration (time) and cost was taken from contract document with the help of project manager. Based on available alternate options of all project's activities, there are 55296 different ways to deliver the project. Proposed fuzzy resource constrained TCT model was applied to find Pareto optimal solutions i.e. optimal combinations of alternatives of activities to deliver the project successfully. The model can be considered as resource constrained as only available alternative resources can be used. No another resource will be used in any activity.

Table 2 Case study project details

				Resources (in Unit)			Time (in Days)			Cost (in Lakhs)		
Act. ID	Activity Name	Successor	Alternatives	r1	r2	r3	t1	t2	t3	c1	c2	c3
1	Mobilization and setup	2	1	4	6	3	5	6	8	5	4	3
			2	4	7	9	6	8	9	4	3	2
2	Site Clearance	3	1	3	7	7	4	6	7	6	5	4
			2	5	8	9	3	4	6	5	4	3
3	Setting out and survey works	4	1	8	4	3	5	7	8	4	3	2
			2	6	6	5	7	9	13	2	3	4
4	Embankment Construction	5	1	5	2	8	8	12	14	22	25	27
			2	6	3	6	9	10	13	21	23	24
5	Subgrade Preparation	6	1	2	6	3	14	17	19	21	24	26
			2	6	7	5	18	20	21	20	21	22
6	Granular Sub Base Preparation	7	1	7	4	8	17	19	21	26	29	31
			2	5	5	9	19	21	24	25	26	27
			3	6	4	7	20	23	25	23	24	26
7	Base Course Preparation	8	1	4	7	9	16	18	21	26	29	31
			2	3	7	7	18	21	22	25	26	27
8	Wet Mixed Macadam	9	1	5	8	9	12	16	18	26	30	33
			2	8	4	3	13	15	18	21	22	23
			3	6	6	5	14	16	19	19	21	22
9	Dense Bituminous Macadam	10	1	5	2	8	7	9	13	8	10	12
			2	4	7	9	8	12	14	7	9	11
			3	6	7	5	9	10	13	6	8	10

			4	7	4	8	13	15	18	5	7	9
10	Tack Coat	11	1	5	5	9	7	9	10	6	7	8
			2	6	4	7	8	10	11	5	6	7
			3	4	7	9	9	10	13	4	6	8
11	Bituminous Concrete	12, 13	1	5	2	8	4	6	7	7	6	5
			2	6	3	6	3	4	6	6	5	4
12	Shoulder	13	1	2	6	3	5	7	8	5	4	3
			2	6	7	5	7	9	13	3	4	5
13	Road Marking	-	1	7	4	8	8	12	14	5	6	7
			2	5	5	9	9	10	13	4	7	8

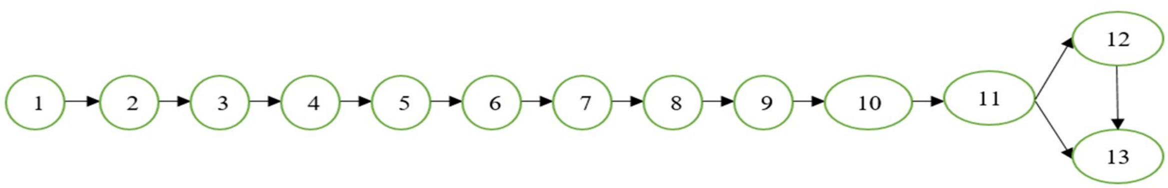

Fig. 3. Project Network Diagram

At first, the fuzzy time and cost were converted into the crisp out with the help of fuzzy alpha cut approach. The alpha value was input as 0.2 as the project manager considers 20% risk in the project. The, the proposed MOGA based fuzzy TCT was practically implemented using MATLAB R2020a. For finalizing the values of MOGA parameters, numerous trials were executed with varying values of these parameters. The best possible combination of MOGA parameters were adopted and shown in Table 3.

Table 3. Adopted values of MOGA parameters

MOGA Parameters	Value
Population Size	100
Number of Generation/Iteration	150
SBX Probability	1
SBX distribution index	20
PM probability	1
PM rate	1/13
PM distribution index	20
Number of division per objective	8

Total 8 exclusive Pareto optimal solutions i.e. 8 unique optimal combinations of activity alternatives were obtained that met the desired project's objectives. PT and PC were determined for each of 8 ways to deliver the project. PT values varies from 138.04 to 152.08 days, while PC values varies from 156.63 to 174.25. All 8 obtained Pareto-optimal solutions are presented in Table 4. Trade off plot between time-cost is also shown in Figure 3.

Table 4. Obtained Pareto-optimal solutions

Sr. No.	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	Time (in Days)	Cost (in Lakhs)
1	1	1	1	1	1	2	1	1	3	2	1	2	1	138.04	174.25
2	1	2	1	1	2	1	1	2	2	2	1	2	2	138.20	166.62
3	1	1	1	1	1	3	1	2	2	2	2	2	2	138.59	165.16
4	1	2	1	1	2	3	1	2	1	2	2	2	2	139.46	162.53
5	1	2	1	1	2	1	2	3	3	3	2	1	1	140.92	160.62
6	1	1	2	2	2	2	2	2	1	2	2	2	2	144.27	160.54
7	1	1	2	1	2	3	2	2	3	3	2	2	1	147.91	158.99
8	2	1	2	2	2	2	2	2	4	3	2	2	2	152.08	156.63

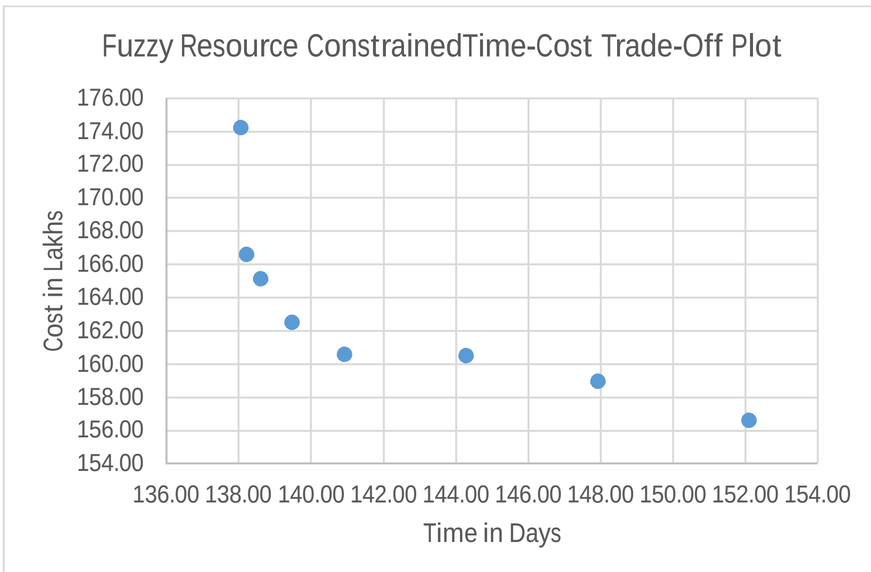

Fig. 3. Fuzzy Resource Constrained TCT Plot

VI. CONCLUSION

In every construction project, the time and cost are the two most important objectives/factors to be considered. In recent years, several studies have been conducted to optimize the time and cost of project under constraint conditions of resources. Since most studies assume the time and cost as deterministic parameters, uncertainties should be considered in estimating the time and cost of the project's activities when minimizing the duration and cost of the project. For this purpose, this study has suggested the fuzzy logic to handle the uncertainties in estimating the time and cost. Besides, the multi-objective genetic algorithm (MOGA) is used to develop the resourceconstrained time-cost trade-off model. Alpha-cut approach is utilized to define the accepted risklevel of decision maker.

The efficiency of the proposed model is demonstrated through solving a case study project of highway construction. The results of case study project illuminates the following capabilities of proposed model.

First, the time and cost of the project can interact with each other which makes it important to optimize them together in constraint resource conditions.

Second, MOGA is found suitable in order to solve the multi-objective optimization problems.

Third, the proposed model is found effective in generating satisfactory and quality Pareto-optimal solutions.

Fourth, proposed model also assists in selecting the one solution from Pareto-optimal solutions.

Fifth, Fuzzy logic is found the best to handle the uncertainties in the estimation of time and cost.

Finally, this study feasibly provides a sound tool to construction organizations for worthy decision making in project scheduling.
Though the proposed Fuzzy TCT model is systematically established to determine the quality Pareto optimal solutions, its usefulness and applications in multi and large scale construction projects are however to be verified.
Additional revision is also requisite with taking the quality, environmental impact and other project's objective as uncertain. Further study is also necessary after adding one or more projects' objectives such as safety others. Real time scheduling is also a future scope of work in construction project management.

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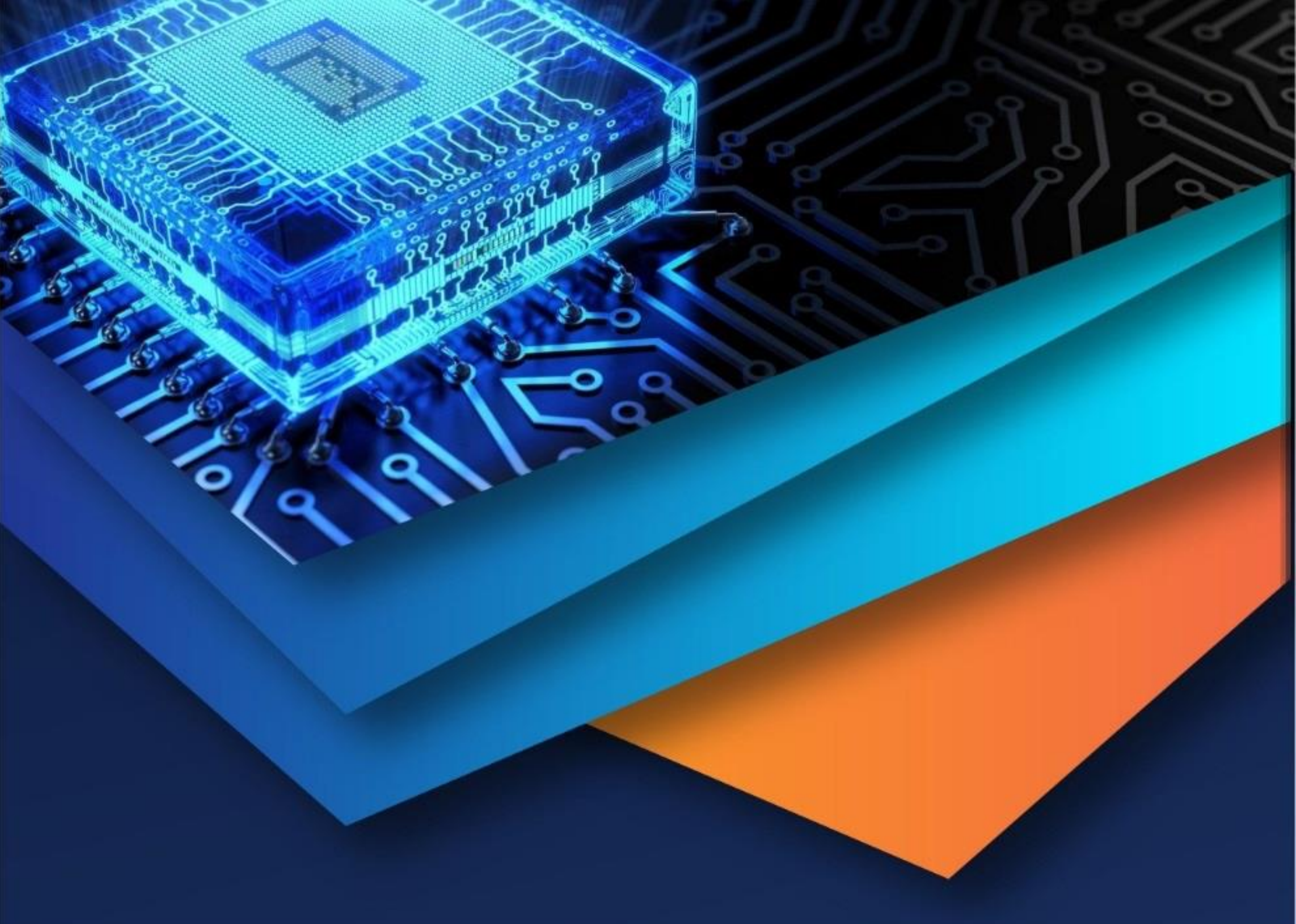

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