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Development of Time-Cost Trade-off Model using Simulated Annealing

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Abstract: In construction projects, reduction of time and cost of any project are very important aspect. Many researchers aimed to develop time cost trade-off models for the success of construction projects. This is a challenging task in the construction field because of uncertainties which affect the project cost. In the construction project's the main objectives are to reduce the time and cost of the project with increasing the productivity of the construction work. Different hybrid methods of multi objective optimization such as genetic algorithm, particle swarm optimization, ant colony optimization have been broadly used for the study of time-cost trade-off problems. In this study a new approach the simulated annealing algorithm is used to solve the time-cost trade-off problem by using MATLAB software to code the mathematical problem. Besides, a case study is used to demonstrate the applicability of proposed model. Furthermore, this paper also provide some recommendations to reduce the completion time and cost of project.
Keywords: construction projects, time-cost trade-off, simulated annealing, MATLAB.

I. INTRODUCTION

Necessity of controlling and optimizing the project objectives is the main cause of gradual development of construction project management (Shi et al., 2010). Time and cost are the main objectives of construction project. Time-cost trade-off problems of a construction projects are vital issues to project accomplishment and has been ever taken into consideration by project managers. Time and cost are critical objectives in the construction project management, are not independent but intricately related. In general, when the duration of construction project is reduced, the project will increase labour demand and extra productive equipment and require more demanding procurement and construction management and then ultimately the result will increase the cost of the project. Time-cost optimization is a process to identify best possible solution for both time and cost. Since there is a hidden trade-off relationship between project time and cost, it might be difficult to predict the total cost of the project will increase or decrease as a result by compressing the schedule of the project. Since different combinations of possible durations and costs for the activities can be associated with a project, the problem is which of these combinations the best are. Determining the best sets is the goal of time-cost optimization.

In the literature, many models have been proposed to solve this combinatorial optimization problem. Feng *et al.* (1997), Zheng *et al.* (2004) developed a genetic algorithm and Pareto-front based approach to solve time-cost trade off (TCT) model. Yang (2007), Zhang and Li (2010) proposed a multi-objective particle swarm optimization (MOPSO) based TCT model. Anagnostopoulos and Kotsikas (2010) experimentaly evaluated the simulated annealing algorithm in solving TCT problems. Xiong and Kuang (2008), Li and Li (2013) presented multi-objective ant colony optimization based Pareto-front approach for TCT problems. Fallah-Mehdipour *et al.* (2012) concluded that NSGA II outperform the MOPSO in determination of Pareto-front for TCT and TCQT optimization. Shahriari (2016) applied NSGA II in discrete TCT optimization problem. Afruzi *et al.* (2013) solved multi-mode resource-constrained discrete time-cost trade-off problem using adjusted fuzzy dominance genetic algorithm. Despite of these several time-cost trade-off models, a new simulated annealing based time-cost trade-off model is proposed in this paper.

II. SIMULATED ANNEALING

Simulated annealing (SA) is a probabilistic technique for approximating the global optimum of a given function. Specifically, it is a metaheuristic to approximate global optimization in a large search space for an optimization problem. It is often used when the search space is discrete (e.g., the traveling salesman problem). For problems where finding an approximate global optimum is more important than finding a precise local optimum in a fixed amount of time, simulated annealing may be preferable to alternatives such as gradient descent. The name and inspiration come from annealing in metallurgy, a technique involving heating and controlled cooling of a material to increase the size of its crystals and reduce their defects. Both are attributes of the material that depend on its thermodynamic free energy. Heating and cooling the material affects both the temperature and the thermodynamic free energy. Simulated annealing can be used to approximate the global minimum for a function with many variables.

A procedure that is called now Simulated Annealing was developed by M. Pincus in 1970 who proposed to employ the Monte Carlo sampling based on Metropolis et al. algorithm (1953) to find the global minimum of a function of many variables. The Metropolis algorithm was developed to determine the equilibrium state of multi-atomic systems— the Markov chain generated by their sampling method converges to the average over the Gibbs ensemble providing the free energy minimum at the given temperature. Pincus emphasized an analogy of his optimization method to the statistical mechanics that directly follows from the very nature of Metropolis algorithm. Based on above, rest of paper is organized as follows: first, research objectives are defined then existing optimization techniques are explained. Then, Research methodology, case study and some recommendations to reduce the completion time and cost of project are detailed. In final section of paper, conclusion and scope for future work is detailed.

III. RESEARCH OBJECTIVES

The objectives of this research are given as follows:

A. Extensive literature review of existing time-cost trade-off models.
B. Study of optimization techniques.
C. To develop a simulated annealing based time-cost trade off model.
D. To implement the developed model on MATLAB.

IV. OPTIMIZATION TECHNIQUES

Literature study shows mainly three methods of project scheduling i.e. Deterministic methods, heuristic methods and meta-heuristic methods:

A. Deterministic Optimization Techniques

These methods/techniques provide exact solutions. In deterministic techniques, the relationship between time and cost of an activity is assumed to be either: linear/nonlinear, concave/not fixed, discrete/ continuous, or a hybrid of the previously mentioned. Four main types deterministic optimization techniques are distinguished in the construction management field:
1) CPM/PERT
2) Linear programming
3) Integer Programming
4) Dynamic Programming

B. Heuristic Method

Heuristic methods are based on historical practice of problem solving. Fondhahl's approach, siemens approximation and structural stiffness method are prevailing heuristics methods of scheduling.

C. Meta-Heuristic Methods

A meta-heuristic is a fixed of algorithmic principles that can be used to outline heuristic techniques applicable to a huge set of various problems. A meta-heuristic can be seen as a well-known standard purpose heuristic method towards promising regions of the search area containing notable solutions. A meta-heuristic is a standard algorithmic framework which can be implemented to different optimization problems with notably few changes to make them adapted to a specific trouble. Various meta-heuristic optimization methods are enumerated below-
1) Genetic Algorithm
2) Non-dominated sorting genetic algorithm
3) Particle Swarm optimization
4) Ant colony optimization
5) Simulated annealing algorithm
6) Cuckoo search algorithm

After a detailed study of optimization methods, simulated annealing is chosen for development of time-cost trade-off model. Basics of simulated annealing algorithm are explained in section II.

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V. RESEARCH METHODOLOGY

A Construction project consists of a number of activities (Singh and Ernst 2011) and each activity has several alternatives to be execute (Elmaghraby, 1977). Since, a limited but different amount of resources is allocated to each alternative. Therefore, each alternative is different in completion time and cost. Besides, each activity should be executed through only one of its alternative. It is therefore necessary to allocate a suitable alternative to each activity

In proposed methodology, each solution is represented as a chromosome of decision variables equals to number of activities. For instance, suppose a construction project has seven activities and each activity has three alternatives through which it can be executive. Based on permutation theory there will be 3^7 ways to deliver the project. If 1-7 activities of construction project are executed with alternatives 2,3,1,2,3,3,1, then a chromosome representing the solution of possible way for project deliver is shown in figure 1.

A-1	A-2	A-3	A-4	A-5	A-6	A-7
2	3	1	2	3	3	1

Fig.1 Possible chromosome solution

Solution string showing in figure 1 is called chromosome and each block of chromosome is called as gene. Each gene consists of number of alternative of respective activity. In GA, value of each gene is called as allele. Hence, activity A-1 is executed by its 2nd alternative, activity A-3 is executed by 3rd alternative and so on.

Since, objectives of this paper are to minimize the time and cost of project, these are formulated as follows:

1) *Project Time (PT):* Precedence diagramming method (PDM) is used to calculate project time in this paper. PDM is based on critical path (CP) of activity on node (AON) network, PT is the summation of completion time of all activities in critical path of activity on node network.
2) *Objective 1:* Minimize T = $\sum_{A\in CP} act_A$ (i)

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

3) *Total Cost of project (TC):* Total cost of project is equal to sum of direct cost and indirect cost of project. Direct cost incurred the cost of material, equipment and labour. Whereas, indirect cost of project include overhead expenses and outage losses.
4) *Objective 2:* Minimize TC = $\sum_A D.C$ + I.C per day × T in days (ii)

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

The procedure to solve time-cost trade-off problem is designed in following steps:

a) *Step-1:* Collection of data: - In the first step, data relevant to construction project is collected. Duration and cost of each alternative of activity is recorded from contract document.
b) *Step-2:* Encoding of solution: - Integer coded chromosome are used as solution of construction project scheduling. Each gene of chromosome represents the alternative allocated to respective activity.
c) *Step-3:* Setting of initial temperature: - An initial temperature ($T_{initial}$) is set before optimization process.
d) *Step-4:* Generate a random chromosome: - Let 'N' chromosomes are possible for delivering the construction project, these are Ch1, Ch2_ _ _ _ ChN. An initial chromosome [X1, X2, X3 _ _ _ XA] is generated randomly , where A is total number of activity in construction project. X1,X2.......Xn represent the alternatives of activities. Time T1 and total cost TC1 of this chromosome is calculated by using objective functions.
e) *Step-5:* Generate another chromosome randomly: - Another chromosome is generated randomly. Let this chromosome is Chn.
f) *Step-6:* Generate a chromosome between Chn and ChN: An another chromosome (Ch2), neighbour of Ch1 with respect to time, is randomly generated between Chn and ChN. Time T2 and total cost TC2 of Ch2 is also calculated by using objective functions.
g) *Step-7:* If TC2< TC1, then accept the chromosome, otherwise the metropolish criteria should be applied. In metropolish condition, probability of accepting the Ch2 is calculated by using following formula-

$$\Delta = exp\left(\frac{TC1 - TC2}{T_{initial}}\right)$$

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Then, A random number is randomly generated in the range [0,1]. If value of Δ is greater than random number between 0 to 1 then Ch 2 is accepted. Thus, in this step, an acceptable chromosome is generated.

h) Step-8: For generating a list of acceptable chromosomes, step 5 to step 7 are repeated again and again with decreasing the temperature in optimum way in each repetition.

i) Step-9: After generating a list of acceptable chromosome, that chromosome is selected as solution of construction project scheduling whose total duration is equal to desired project's duration. If list of acceptable chromosomes consists of more than one chromosomes of desired project's duration then chromosome of minimum total cost is selected and proposed as solution of construction project scheduling.

VI. CASE STUDY AND RESULT ANALYSIS

To demonstrate the working of proposed simulated annealing based time-cost trade-off model, it is practically implemented on a case study project. This project consisted of eleven activities with several alternatives. Complete details of case study project are given in table 1.

Table 1. Details of case study of project

ID	Activity	Successors	Alternative	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	Footing	-	1	16	28341.60
			2	12	45616.48
			3	8	36554.88
9	Exterior Finish	-	1	31	69659.78
			2	23	233034.50
10	Interior Finish	-	1	3	4006.80
			2	4	1746.55
11	Roof	8,9,10	1	21	117851.84
			2	23	69253.17

Based on permutation theory, there will be 9216 ways to deliver this project. To determine the optimal way to deliver the project look manually impossible. So, the proposed methodology is coded in MATLAB_R2018ax64 software. Then, proposed simulated annealing base time-cost trade-off model was practically implemented on above case study project. Project desired duration was considered as 91 days. At 91 days, minimum project cost was find out as 476,588 US $. While, at different-different project duration, minimum project cost found as follows given in table 2.

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Table 2. Cost of project at different-different time

Sr. No.	Time (Days)	Cost (US$)
1.	83	641901
2.	85	600926
3.	87	597340
4.	88	593418
5.	90	578171
6.	91	476588
7.	92	470313
8.	93	435249
9.	95	427920
10.	97	423114
11.	99	419749
12.	100	411487
13.	101	411467
14.	104	410183
15.	106	405397
16.	107	403256
17.	109	401263

Based on time-cost values obtained in table 2, time-cost trade-off curve is plotted as figure 1.

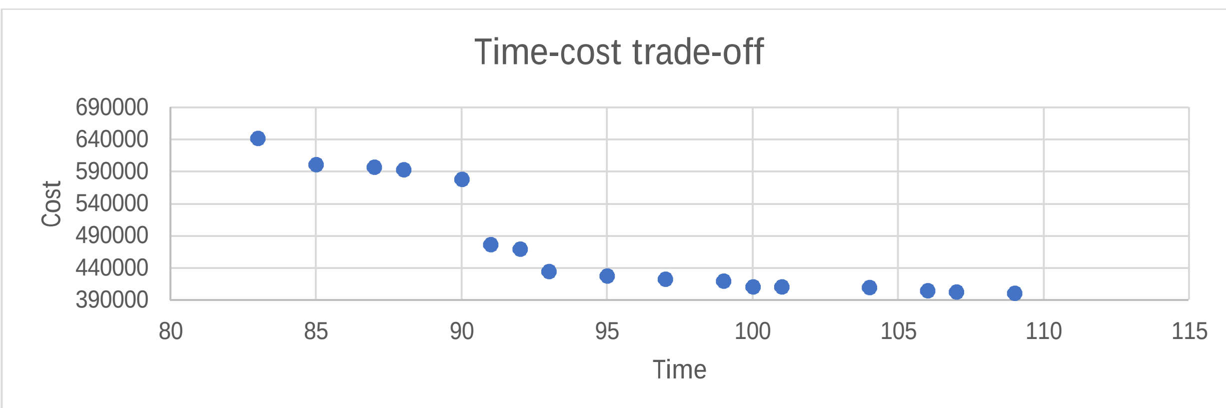

Figure 1 Time-cost trade-off curve for case study project

VII. RECOMMENDATIONS FOR REDUCING CONSTRUCTION PROJECTS TIME AND COST

Although the construction projects are largely profitable business, bad planning and poor project management can increase the time and cost. Understanding and managing cost is critical for profitable outcome.

1) *Clear project planning and Design* – The ultimate target of planning is to obtain a rigid construction plan that may largely optimize the chance of upcoming changes. Examining by what means the cost of revision raises as a project advances. Planning should include a detailed enough budget that can be used to determine profitability. Construction can take months to years, raw material and labor rates are subject to variation. Plan for it and try to reduce financial risk by locking variable costs down like rates at the time of acquiring services and materials where you can.
2) *Hire qualified and experienced professionals* – Whenever looking at construction contractors, architects or interior designers, it is always a good idea to hire qualified and experienced professionals who have been in the business long enough to be thoroughly skilled and to have the knowledge of the best and latest practices in the market.
3) *Employ diversely skilled staff* – One way to reduce downsizing is with smart hiring, acquire key people with a diverse skill set and create a work culture that feeds and supports cross training and professional development. Investing in skill diversification gives you a workforce that can adapt to changing work requirements without hiring additional people.

4) *Reducing your fleet* – If Construction Company has a large vehicle fleet, chances are that you are incurring significant costs that range from preventative maintenance to insurance. Construction fleets have their own unique set of costs that include fuel, maintenance, liability and others.
5) *Acquisition* – The acquisition construction project part is a good stage to bring into the basics of estimate with raw materials and stock. In common, a rigid acquisition planning may target in proportion cost, ease, fast as well as quality build upon the projects distinct uncertainty and objective.
6) *Brace for Modify Request* – Firstly and most important, to bypass major modification request, it must be ascertain that we must have exhaustive and finished designs, with good margins for changes. Additionally, initial association with all the project stakeholders understands the difficulties of the proposed plan and may enquire as soon as the construction really starts.
7) *Construction Labor* – Labor cost is also a large part of the construction which can not cut easily. But try to calculate the works in hours how much labor will be required to finish work and how much time.
8) *Equipment* – Equipment and vessels are more like assets; good quality machine will have their cost for a long period. Low cost equipment may cost less in the starting of a project but they can increase the overall cost of the project by means of damage, repair and replacement.
9) *Construction Materials* – For construction materials, it is seen that use of fresh and lucrative doesn't give the required results. Being most newer materials are available in the market, it is always better to use those which are proven themselves over a period of time as they are effective in cost and time management. Nevertheless it is always important to consider efficiency in every aspect.
10) *Do Not Make Too Many Changes Midway* – If you decide to change the blueprint for the project once the construction work has started, it could cost you a fair bit. It is always a good idea to take your time to be sure of the plan before the work commences.
11) *Security of Project and Machinery*– Security is one of the major concerns as negligence on this part may cost serious losses which will increase the cost of the Project. Every Team Member of the Project must have the habit to ensure proper shutdown and security of the material at end of the day. They must have the feeling of accountability for the machinery and materials they are using or by mutual agreement they can be held accountable.
12) *Safer Sites* – Evaluation of safety in the site is of foremost importance as it may cause serious damage physically to the site as well as to the workforce.. To ensure the safety of the site one must fallow the Standard Operating procedure (SOP) and use protective gears for his personal safety while on Jobsite.
13) *Using Modern Technologies* – The advent of technology has transformed the realm of the construction in more way then one. Using of new technologies that can save a lot of time and money, while minimizing the scope for human error in construction.
14) *Cleaner Workplace or Jobsite* – It is recommended that clean workplace or jobsite can increase the efficiency of workforce and in turn reduce the cost of the project by a considerable percentage. Human beings always love to work in Conducive Environment and cleaner workplace thereby increasing their productivity and timely completion of the Project.
15) *Material Usage* – Material Usage is key point of any project as it cost more than half of the Project cost. Reducing the wastage of Material and keeping timely inventory can help to save a lot.
16) *Saving on Building Materials* –There are many ways in which you can save on the cost of building materials. For instance, go for locally available bricks, cement, tiles, paints, etc. Invest in low-maintenance construction materials to cut down long-term costs.
17) *Saving in Machinery Cost* – Construction machines are always hired on a rental basis and their rental cost is too high. So try to take maximum advantages of construction machinery in a calculated way by which construction cost can be saved.
18) *Use Fly Ash bricks instead of Red bricks* –If you want to reduce the cost then choose to fly ash bricks instead of red bricks or other bricks. Fly ash bricks are less costlier than red bricks but have good strength for construction. It can reduce the cost of the construction in a considerable amount.
19) *Go for prefabrication work* – To minimize the cost of construction use prefabricated parts for construction. In this type of construction, a part of the building is constructed at the factory or in a separate place and then combined to a site to make the house. It has a lot of benefits. It not only reduces the cost but also reduces the time of construction.
20) *Saving in Finishing Material* – Not only is the construction material only responsible for rising cost. Along with that finishing, the material is also responsible. While we consider finishing work there is flooring material, doors and windows, and especially wooden works for interior absorbs a huge cost. But this can be reduced if you are choosing proper material and buying material in bulk amount at a time.

21) *Confirmation of work Completion* – Before handover of the Project one must ensure that every small bit of work got completed. For a desirable end of the Project large number of pieces and procedures are to be ensured and completed.
22) *Overview the Balance sheet* – Clearing the paid and unpaid Bills before winding up the Project may help in reducing the future legal liabilities and assessing the net profit. So some time must be given for paying the unpaid invoices and fallow up the amount to be received.
23) *Learning from your Shortcomings* – Every Mistake or Shortcoming is a lesson earned as experience for upcoming Project. One must take it as opportunity to learn and eliminate in future Projects.

VIII. CONCLUSION

Making of trade-off among project's objectives is becoming essential due to rapid development in technologies and requirements of stakeholders of project. This research provide a complete framework to optimize the time-cost trade-off in scheduling of construction projects using simulated annealing.

Result of case study illustrate the potential of proposed SA based TCT model.

1) First, relationships between time and cost can be established, which extend the perspective of traditional project control mechanism.
2) Second, SA found appropriate to address the issues of TCT optimization.
3) Third, proposed SA based TCT model can assist the project team and practitioners to select an optimal solution for project delivering. Additionally, this study and proposed TCT will be beneficial to project's participants in perspective of making profit. Finally, this study possibly provide a better scheduling decision making tool for project team and organisation.

Globally, even though proposed SA based TCT is found capable in finding optimal solutions, its effectiveness and significance in large scale and multi construction projects are yet to be tested practically. Further study with taking uncertain time, cost and other project's objective is also required. Further analysis is also essential after adding one or more project's objectives such as safety, risk and others.

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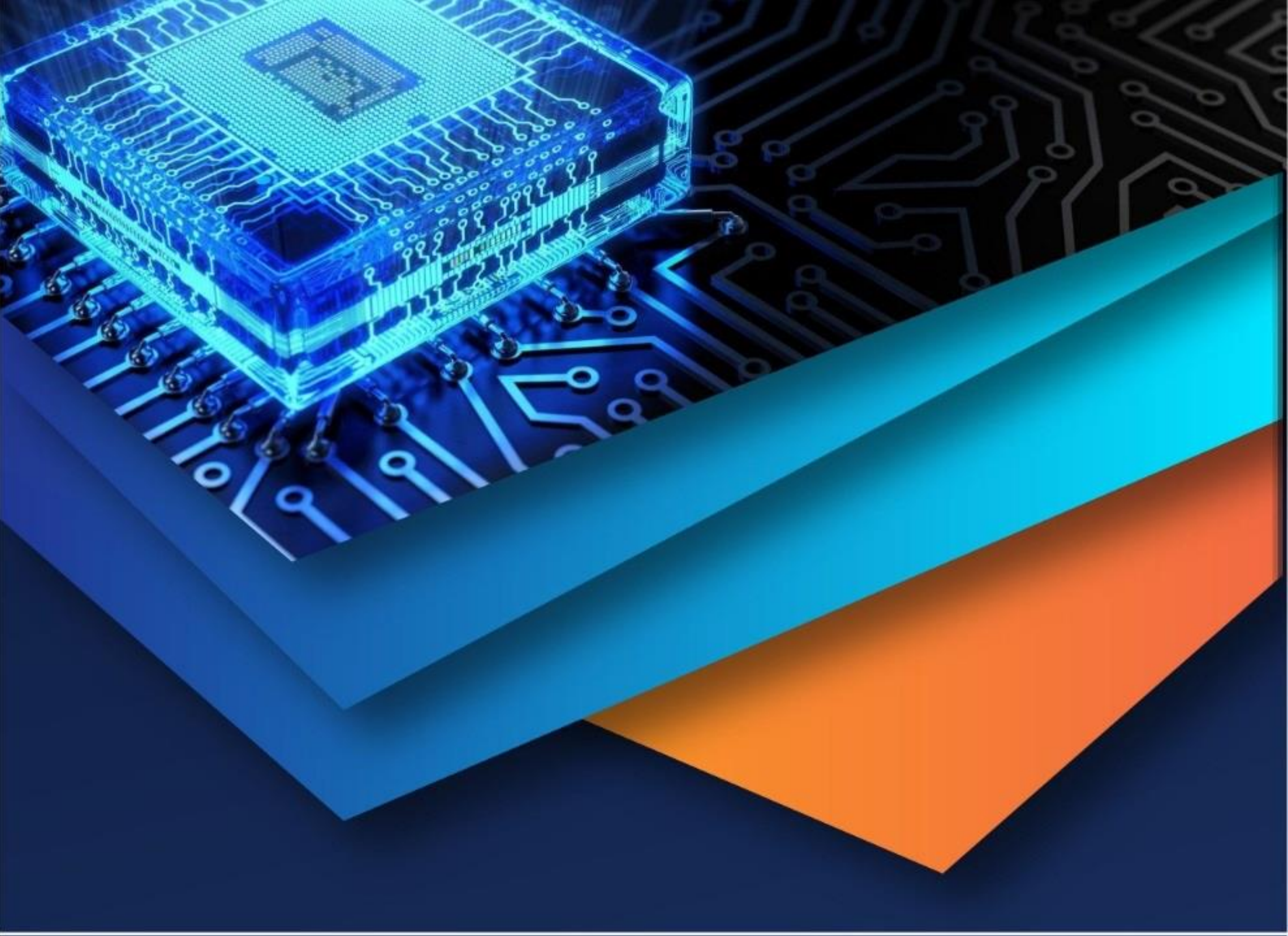

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