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Determination of Quality and Safety in Construction Project consisting Multi-Mode Activities

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Abstract: ***Quality and safety are of paramount importance objectives of construction project after time and cost. Literature shows numerous methods estimating the quality and safety of project numerically. After an extensive literature survey, this paper provide a framework to determine the quality and safety of project through determining the quality and safety in each alternative of each activity. A case study project is used to demonstrate the working of this framework. Besides, this paper present the review of past work conducted for adding the quality or safety or both in the time-cost trade-off models. Review shows safety is rarely added in time-cost trade-off models, while quality is extensively added in time-cost trade-off models. Furthermore, this paper provides some recommendations and suggestions to improve quality and safety parameters in construction project.***
Keywords: construction projects, quality, safety, time-cost trade-off.

I. INTRODUCTION

In construction industry quality may be defined as the achievement of permeable level of outcomes from the construction activities. The outcomes may be achieved when the activity in construction projects fulfils the needs of the owner on the client. In any project quality can be achieved when it ensures the required specification to maintain quality in construction industry is every challenging issue with related to several problems within it swarm. Poor practice management of qualities in construction projects leads to the roots of resources materials money and time.

Definition in other words "The overall quality in construction is quality of materials being used in construction, quality of workmanship, or the completion of end user's ultimate requirements." Schexnayder and Mayo (2004) made some addition in the definition of quality beyond just 'Supplying the right materials' and add that 'construction quality about finishing the project safely on time within budget and without claim and litigation'.

Quality in construction industry can be defined as the achievement of acceptable levels of outcomes from construction activities. Required outcomes would be attained when the activity meets or fulfil the requirement of the client or the owner. The quality of any product or service is attained when it assures to the desired specifications.

Maintaining the quality in construction project is not an easy task. Since, its mainly rely on quality of labour work, equipment performance and material quality. Inefficient or no practice of quality management operations will result in great loss of time, money, material, resources.

The term quality has many implications when it is used by several stakeholders of a project. Some of the ways the quality has been explained below

1) Finish the project within the time
2) Completion of contracts specifications
3) Raise the level of the customer satisfaction
4) Slaves of claims and dispute

In construction quality assurance, there are some predefined schemes which are directly applied in construction to monitor and regulate the quality of construction activities in constant manner. Every company has quality control parameters, which ensure various quality check at different levels. In general quality assurance follows the following measures:

a) Safety program for all workers and employees
b) Confirm training of workers for quality of work
c) Incentive program for innovative works

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Quality control in construction progress includes periodic supervision of activities involve in construction. In any construction projects quality control is achieved by the trained staff with quality engineers.

In any activity of construction project quality control is also a part of good management which contains material process, sampling and inspection. Aim of quality control in construction project have following objectives:

i) It is the full fitness of the aim in any project.
ii) It is assurance to specifications.
iii) It is worth of monetary expenses.
iv) It is the fulfilment of customer requirements.
v) Decrease the variability in the project.

Safety is the situation of being guarded from unwillingly to cause injury, danger or risks. Safety is comes in existence from French word safe (from French word sauf). The circumstance of being secured from or non-acceptable outcomes. Safety is also related to the control of identified hazards in order to obtain acceptable levels of risk. In any organization which is working on at large for small scale coma safety is normative concept.

Safety of every construction site is most overlooked things during construction projects. In most of the workplace accidents are nuisance for the workers and also for company management. In construction sites, accidents are like threatening which cause loss of life workers doing job at the site.

There are various accidents occurs at construction sites in which we can includes Earth shattering, explosions, environmental disasters, structural failure, mishandlings of materials, trapped labor. In all professions construction works most dangerous that's why most of the accidents occurs on construction site. It is necessary for the employer to overcome safety hazards for case the labor have to follow precautions for themselves when they are working in hazards conditions.

- Awareness
- Supervision
- Proper equipment
- Training
- Communication
- Transparency
- Documentation

II. DETERMINATION OF QUALITY AND SAFETY

In construction project, a number of activities have to be finished for project completion. An activity (A) can be completed through one of its available alternatives. Each alternative of an activity has different completion time, completion cost and effect on whole project quality and safety due to variation in amount of resources associated to each alternative. Entire project quality and safety are determined in terms of project quality index (PQI) and Project safety risk (PSR) respectively. PQI and PSR are determined as follows:

1) *Project Quality:* This QST optimization model is deliberated in such a way that it can quantify the construction project quality in terms of Project Quality Index (PQI). PQI depends upon the quality achieved in completion of each activity. PQI can be calculated by using equation of (El-Rayes and Kandil, 2005) as follows:

$$PQI = \sum_{A=1}^{n} wt_A \cdot \sum_{k=1}^{k} wt_{A,k} \cdot Q_{A,k}^{m} \quad \text{(vii)}$$

Where $Q_{A,k}^{m}$ is performance of quality indicator *(k)* in activity *(A)* using resource utilization *(m)*; $wt_{A,k}$ is weight of quality indicator *(k)* compared to other indicators in activity *(A)*; and wt_A is weight of activity *(A)* compared to other activities in the project. Generally an activity has many quality indicators such as labour, material equipment, etc…. For instance, quality performance of labour, material and equipment are 85; 90; 70, respectively. The corresponding weights of quality indicators are 0.50, 0.20 and 0.30. If the weight of activity in total project is 0.15 (15%) then AQI is calculated as [(0.85*0.50 + 0.90*0.20 + 0.70*0.30)]*0.15 = 0.122.

2) *Project Safety:* Project safety is measured in terms of project safety risk (PSR). Project safety risk is calculated in three steps. In first step, most relevant safety risks of project associated with alternatives of activities are identified. In second step, on expert's perspective probability and consequence of identified safety risks are evaluated in terms of risk rating system. For this purpose, six point risk rating system (Cookee and William, 2013) is used as shown in table1.

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Table 1. Safety risk rating system

Probability		Consequence	
Probability Description	Score	Consequence Description	Score
Remote	1	Minor Injury	1
Unlikely	2	Illness	2
Possible	3	Accident	3
Likely	4	Reportable Injury	4
Probable	5	Major Injury	5
Highly Probable	6	Fatality	6

In last step, PSR is calculated by using following equation-

$$\sum_{N=1}^{N}\sum_{k=1}^{k} \cdot \sum_{i=1}^{i} P_{Aki} \cdot C_{Aki}$$

Where, P_{Aki} is the probability of occurring safety risk *i* in k^{th} alternative of N^{th} activity. Generally, an activity has labour injury risks, material wastage and losses risks and equipment failure risk.

III. CASE STUDY

Proposed methodology is applied on a under construction 3-storeyed case study project. ID, Name, successor, alternatives, values of quality and safety indicators are given in table 2. At different-different combinations of alternatives of activities, PQI and PSR are presented in table 3.

Table 2. Details of case study project

				SI k = 1		SI k = 2		SI k = 3			QI k = 1		QI k = 2		QI k = 3	
ID	Activity	Successors	Alt	RL L_k mA	RS S_k mA	RL L_k mA	RS S_k mA	RL L_k mA	RS S_k mA	Act. weight wt_A	IW $(wt_{A,k})$	QP $(Q^m_{A,k})$	IW $(wt_{A,k})$	QP $(Q^m_{A,k})$	IW $(wt_{A,k})$	QP $(Q^m_{A,k})$
1	Site Clearance	2	1	1	1	1	1	1	1	0.05	0.45	97	0.30	99	0.25	93
			2	1	2	1	2	1	2			70		73		71
2	Excavation	3	1	3	3	1	1	3	2	0.08	0.20	94	0.35	91	0.45	89
			2	3	4	2	1	4	3			83		88		84
3	Footing	4	1	3	2	4	2	3	2	0.10	0.30	95	0.45	94	0.25	95
			2	2	2	3	3	3	2			72		74		78
4	Formwork	5	1	3	5	2	1	2	2	0.06	0.35	89	0.35	92	0.30	94
			2	2	4	3	2	3	4			83		83		87
5	Retaining wall	6	1	3	3	2	2	1	2	0.09	0.30	85	0.35	92	0.35	95
			2	2	4	3	3	1	1			78		86		89
6	Basement	7	1	2	3	4	5	3	3	0.08	0.40	99	0.30	78	0.30	94
			2	3	4	4	6	4	4			73		85		67
			3	4	5	5	6	3	3			60		90		86
7	Slab	8	1	4	5	3	3	3	4	0.10	0.40	94	0.40	93	0.20	87
			2	4	6	4	4	4	4			71		69		96
8	Exterior wall	9	1	2	3	2	4	2	3	0.08	0.40	90	0.50	78	0.10	73
			2	2	2	3	3	1	2			85		90		94
			3	2	2	3	2	2	3			90		95		95
9	Interior wall	13	1	2	3	2	4	2	1	0.06	0.40	97	0.50	98	0.10	97
			2	2	2	3	3	1	2			89		96		67

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			3	2	2	3	2	2	2			81		85		63
			4	2	2	3	3	2	3			95		84		90
10	Flooring	–	1	2	3	2	4	2	1	0.07	0.45	85	0.45	90	0.10	78
			2	2	2	3	3	1	2			88		92		90
			3	2	2	3	2	2	3			78		84		93
11	Exterior finish	–	1	2	5	2	2	2	3	0.08	0.40	70	0.50	85	0.10	90
			2	3	6	3	3	3	3			95		88		85
12	Interior finish	–	1	1	2	2	3	1	3	0.07	0.40	70	0.50	85	0.10	90
			2	2	3	3	3	2	3			95		88		85
13	Roof	8,9,10	1	2	3	3	4	2	4	0.08	0.30	98	0.40	95	0.30	99
			2	3	4	4	5	3	5			87		86		83

A MATLAB program was prepared to calculate the PQI and PSR at different-different combinations of alternatives of activities.

Table 3. PQI and PSR at different-different combinations of alternatives of activities

Sr. NO.	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	PSR	1/PQI
1	1	1	2	2	2	1	1	3	4	1	1	1	1	266	2.12
2	1	1	1	1	2	1	1	1	4	1	1	1	1	266	2.09
3	1	1	1	1	2	1	1	3	2	2	2	1	1	273	2.05
4	2	1	2	1	2	1	1	3	2	1	2	1	1	276	2.13
5	1	1	1	1	2	1	2	3	4	3	1	1	1	277	2.12
6	2	1	2	1	2	1	1	3	4	1	2	1	1	280	2.13
7	1	1	1	2	2	1	1	3	4	1	2	1	1	283	2.05
8	1	1	2	2	2	2	1	1	2	1	1	1	1	283	2.11
9	2	2	1	1	2	1	2	3	2	1	1	1	1	286	2.16
10	1	2	1	2	2	1	1	1	4	1	2	1	1	297	2.05
11	1	1	1	2	2	1	2	3	4	1	2	1	1	298	2.08
12	1	1	1	2	2	1	2	1	4	3	2	1	1	302	2.08
13	1	1	1	2	2	2	2	1	4	1	1	1	1	303	2.12
14	1	1	2	1	2	3	2	1	4	3	1	1	1	304	2.14
15	1	1	2	1	2	3	2	3	2	2	2	1	1	311	2.11
16	2	2	2	2	2	2	2	3	4	1	1	1	1	311	2.20
17	1	1	1	1	2	1	2	1	2	1	2	1	2	314	2.11
18	1	1	2	1	2	3	2	1	4	2	2	1	1	319	2.11
19	1	1	2	2	2	1	2	1	4	3	2	1	2	322	2.15
20	1	1	2	2	2	1	2	1	4	3	2	1	2	322	2.15
21	2	1	1	2	2	1	2	1	4	3	2	1	2	326	2.17
22	1	1	2	2	2	3	2	3	4	3	1	1	2	326	2.19
23	1	1	2	2	2	2	2	3	4	1	2	1	2	335	2.15
24	1	1	1	2	2	3	2	1	4	3	2	1	2	347	2.12

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IV. REVIEW OF PAST WORK RELATED TO QUALITY AND SAFETY

Literature study shows that mainly three methods are used in purpose of scheduling i.e. deterministic methods, heuristic methods and meta-heuristic methods (Panwar, Tripathi and Jha 2019). Deterministic methods provide exact solutions and include CPM, integer programming (IP), linear programming (LP) and dynamic programming (DP) methods for activities scheduling. Start with history, Kelley and Walker (1959) proposed a critical path method for scheduling the activities of projects. Thereafter, several deterministic methods based scheduling models were developed using CPM (Kallantzis and Lambropoulos 2004), IP/LP (Liu, Burns and Feng 1995; Ipsilandis 2007), and DP (Moselhi and Ei-Rayes, 1993).

Heuristic methods are based on historical practice of problem solving (Zhou *et al.* 2013). Fondhahl's approach (Fondahl 1962), structure model (Prager 1963), siemens approximation (Siemens 1971) and structural stiffness (Moselhi 1993) are prevalent heuristics methods of scheduling. Furthermore, Zhang *et al.*(2006), Elazouni (2009), Di *et al.*, (2013), and Wongwai and Malaikrisanachalee (2011) also made effort to develop heuristic methods based scheduling models.

Meta-heuristics methods of scheduling were developed to solve two or more than two objective problems. In the course of bi-objective optimization, several scheduling models such as time-cost trade off using GA (Li and Love 1997; Feng *et al.* 1997; Hegazy 1999; Zheng *et al.* 2004; Long and Ohsato 2009), PSO (Zhang and Li (2010); Fallah-Mehdipour *et al.* (2012); Aminbakhsh and Sonmez (2016); Albayrak and Özdemir (2018); Liu *et al.* (2020)), Simulated annealing (Anagnostopoulos and Kotsikas (2010); Suliman and Kumar (2012); Milenkovic *et al.* (2012); Glišović (2014)), Ant colony optimization (Kalhor *et al.* (2011); Xiong and Kuang (2008); Ng and Zhang (2008); Li and Li (2013)) and NSGA-II (Fallah-Mehdipour *et al.* (2012); Li and Wu (2014); Shahriari (2016); Li, Xu and Wei (2018)) were developed. Some researchers also dealt with three objective optimization i.e. time-cost-quality trade off explained as follows:

Time-cost-quality trade-off scheduling models: In literature, quality in scheduling problems is extensively added because quality of construction projects may be affected by crashing (Babu and Suresh 1996). In literature, time-cost-quality trade off scheduling models using GA (El-Rayes and Kandil 2005; Shahsavari Pour *et al.* (2010); Mungle *et al.* (2013); Abd El Razek *et al.* (2010)), NSGA-II (Amiri *et al.* (2013), Monghasemi *et al.* (2015)) and PSO (Luong *et al.* (2018); Zhang *et al.* (2014)) were found. Kosztyán and Szalkai (2018) proposed a resource constrained hybrid time-quality-cost trade-off model that cares the traditional and agile project management both. Hu and He (2014) developed a nonlinear time-quality-cost trade-off model using GA. Fu and Zhang (2016) also suggested a new non-linear programming model based on the multi-mode resource constrained project scheduling problem.

V. RECOMMENDATIONS FOR IMPROVING QUALITY IN CONSTRUCTION PROJECTS

A. Skill Training

In spite of the fact that the vast majority of a construction labours abilities can be picked up at work, security is one range of abilities that is best learned before works enter the building site.

The Occupational Safety and Health Administration (OSHA) and different associations distribute a few assets to assist organizations with preparing their new workers on standard wellbeing and security works on, including leaflets, worksheets, preparing recordings, and even nearby preparing chances.

Experienced labours ought to be required to invigorate their insight into standard security by going to customary instructional meetings consistently.

These instructional courses can go over basic things, for example, fall insurance and appropriate utilization of stepping stools, yet the objective is to ensure everybody is sufficiently prepared. Leaving these instructional meetings, labours should follow what wellbeing measure to do on account of an occurrence.

Despite the fact that labours are required to go to ordinary security instructional meetings about construction wellbeing consistently, having the option to rehearse wellbeing preparing aptitudes on location would help construction labourers authorize the security rules.

B. Proper Documentation of Work

To enable construction site security, you need to make sure you have proper documentation of everything that will be done on site. Most construction companies have some legal loopholes to start building, and all formal registrations and licenses must be obtained before work can begin. Supervisors and contractors will be involved in difficult tasks such as blasting, demolition of course they will need to provide their certification prior to working at the employment site. This not only prevents accidents caused by improper training, but also protects the construction company from legal action and public scrutiny.

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C. Availability of Equipment's

To create a culture centred on construction site safety, you need to provide workers with the right equipment and enough work area for the work at hand.

Without the right equipment you can never get construction site protection because there is always a chance of getting injured using the wrong equipment.

Construction workers fitted with improper gear are forced to make dangerous mistakes. Not only must every piece of equipment on the job site be very suitable for the task at hand, but construction companies must ensure that all machinery and materials are well maintained.

D. Inspection Of Equipment's And Tools For Proper Working

Construction labours depend on their equipment to work proficiently and get work done on time without any failure or casualties. If their equipment is unsafe or broken, there are high risks of serious accidents, including loss of limbs. The equipment should be examined frequently to confirm that there are no defects in the equipment. It is the concern of both the employee and owner to find issues with faulty equipment's.

E. Supervision of Work

Preferably, construction workers would completely understand the complications of insufficient safety precautions and thus act in a manner to make sure site safety.

Every site must have a supervisor who is prepared and skilled of enforcing safety principles with no compromises. Supervisor must monitor all workers everywhere all over the day and right the individuals who neglect to focus on legitimate building site security techniques.

F. Introduce Additional Resources And Innovative Technologies

The casualty rate would be much higher than it is today if not for construction firms ready to dedicate additional assets to guard their workers.

These extra assets not just lower the paces of work environment calamities and wounds yet additionally grows new thoughts for protecting construction labours.

The advancement of new practices that will upgrade security ought to consistently be energized, and organizations ought to abstain from criticizing performing planned for improving wellbeing conventions.

Maybe with enough advancement, all building destinations can expand their building site security rehearses and can be totally casualty free.

G. Proper Communication and Transparency of Work

The most noticeably unpleasant thing any construction firm can accomplish for its bad reputation is endeavouring a concealment. Eventually, individuals understand that mishaps occur, and as long as contractual workers are putting forth a courageous effort to encourage a sheltered situation for their labours, any mishaps that do happen will just add to the developing need to expand present day security strategies.

A more secure construction industry is an industry of less wounds, less working environment mishaps, and less passing. Construction companies would be insightful to outfit labourers with gadgets, as cell phones, walkie-talkies, or headsets, which permit quick and effective correspondence among colleagues.

Clear and compact correspondence with everybody causes the undertaking to pass by quicker as well as helps keep every individual educated. Advising the staff and ensuring everybody is carrying out their responsibility is an appropriate method to convey and ensure they comprehend construction site security.

H. Safety and Health Precautions and Practices

Construction labours working in high and medium hazard conditions are required to have adequate health and security preparing. They ought to be completely skilful and mindful of the dangers related with their activities, particularly when working at tallness, with hardware or in bound spaces.

It is additionally exhorted that they have a fitting familiarity with emergency treatment, having the option to regulate fundamental life-sparing strategies if important.

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I. Demonstration of Clear Signs and Notations

Construction sites are full of potential hazards, not only for labours but as well as for the public. It is essential to highlight any danger with marks and pictures, which warns everybody close to take precaution. Notation and Signs are economical technique of decrease accidents, which can show hazards such as dropping objects, rotating large vehicles or the being there of gas / chemical compounds.

J. Use of Personal Protective (PPE) Equipment's

Required staff assurance hardware (PPE) must be worn consistently when on construction site. At least, every representative is required to wear a hard cap and wellbeing glasses. High deceivability wellbeing vests with intelligent striping are required when representatives are presented to vehicular traffic. In the unlucky deficiencies of vehicular traffic, high deceivability shirts ought to be worn consistently. All specialists must wear shirts with sleeves, long work jeans, and tough work shoes or boots when taking a shot at a development or redesign site. Sleeveless or tank top shirts, short jeans, workout pants, tennis shoes, shoes, and high-behaved or open-toed shoes are not allowed. If all this preventive measures taken into account the chances of accidents and calamities can be reduced at construction workplaces.

VI. RECOMMENDATIONS FOR IMPROVING SAFETY ASPECTS IN CONSTRUCTION INDUSTRY

A. Skill Training

In spite of the fact that the vast majority of a construction labours abilities can be picked up at work, security is one range of abilities that is best learned before works enter the building site. The Occupational Safety and Health Administration (OSHA) and different associations distribute a few assets to assist organizations with preparing their new workers on standard wellbeing and security works on, including leaflets, worksheets, preparing recordings, and even nearby preparing chances. Experienced labours ought to be required to invigorate their insight into standard security by going to customary instructional meetings consistently. These instructional courses can go over basic things, for example, fall insurance and appropriate utilization of stepping stools, yet the objective is to ensure everybody is sufficiently prepared. Leaving these instructional meetings, labours should follow what wellbeing measure to do on account of an occurrence.

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Construction sites are full of potential hazards, not only for labours but as well as for the public. It is essential to highlight any danger with marks and pictures, which warns everybody close to take precaution. Notation and Signs are economical technique of decrease accidents, which can show hazards such as dropping objects, rotating large vehicles or the being there of gas / chemical compounds.

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VII. CONCLUSION

Construction industry plays an important role in the development of economy of any nation. Therefore, it is necessary to complete the project in minimum time and cost. However, time and cost of project vary due to variation in the resources. Quality and safety of project is also affected by crashing of project. Therefore, it is necessary to balance the quality and safety of project with balancing the time and cost of project. Before balancing the quality and safety of project, it is required to numerically determine the quality and safety of project. In this regard, this paper provides separate equations determining the quality and safety of entire project in terms of project quality index (PQI) and project safety risk respectively (PSR). A case study project is used to demonstrate the working of equations. Moreover, construction projects are generally carried out under open surrounding, tight constraint of time and cost and highly technological resources. Therefore, it becomes necessary to maintain the quality and safety in project throughout the entire lifecycle of project to prevent the accidents in construction. Labour injury risks, material wastage risks and equipment failure risks are three main safety risks. To alleviate, this paper provide some recommendations and suggestions to improve the quality and safety of project. This study will be beneficial to construction managers to make decisions for maximizing the project quality and minimizing the project safety risk in construction work.

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However, several scheduling models were developed to make time-cost, time-cost-quality and time-cost-safety trade-off models, whereas lack of studies were conducted to integrate the quality and safety together in trade-off models.

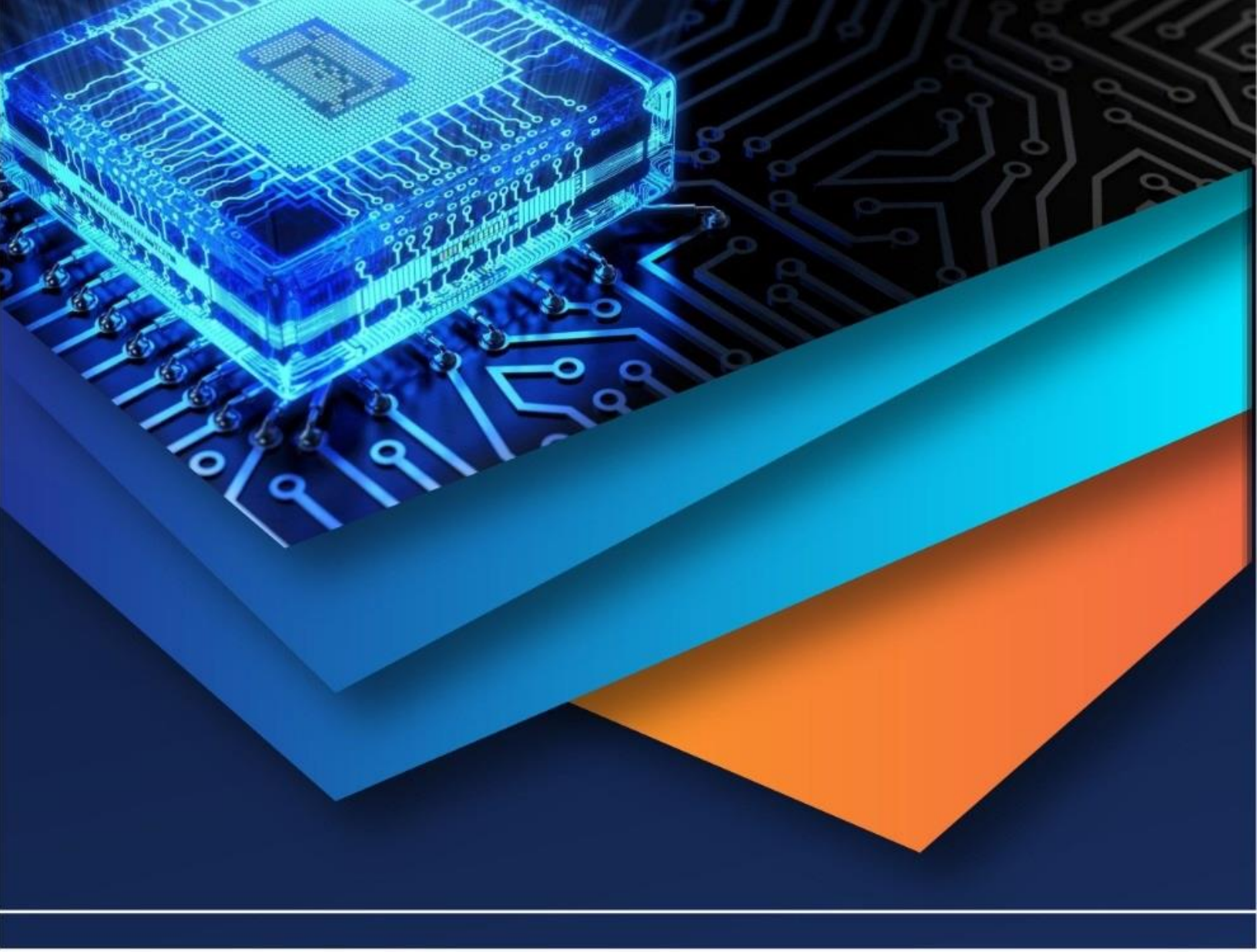
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