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Risk Management in Highway Construction using Fuzzy Logic and ISO31000:2018

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Abstract. Highway construction projects play very important role in social, economic and cultural development of any country. These projects undergo many risks during construction process, so it is required to manage these risks before starting any highway construction. This research presents a complete framework for managing risks in highway construction projects using Fuzzy Logic and ISO 31000:2018. During the last few decades, significant amount of attention has been given to manage the risks in projects especially in highway construction projects. To date, many methodologies considering the risk occurrence, risk consequences and risk detectability have been proposed in literature to quantify and manage the risks in highway construction projects. On the other hand, as per ISO31000:2018 guidelines, risk vulnerability should also be the considered in risk management process. Accordingly, in the present study, a fuzzy logic-based model is developed through MATLAB software to quantify and rank the risk factors of highway construction projects. As fuzzy logic is used, proposed model has the potential to handle uncertainties in all four risk parameters. In order to demonstrate the working of the proposed model, it is practically applied to the three real case studies. Results of case studies provide the ranking of risk factors based on the calculated risk index values. Furthermore, risk strategies and risk allocation plan is also prepared based on the highway projects' experts.
Keywords: Highway construction projects, risk management, fuzzy logic, ISO 31000:2018.

I. INTRODUCTION

The unexpected events that affect the objectives of any process, product, program, operation, and project are called Risk events. Risk management is increasingly relevant in any process, product, program, operation, and project in a changing environment with time (Power, 2007). This shows that each firm needs to be ready to analyse unforeseen events before any project starts. In order to manage the risks, companies are required to tackle the unforeseen events that could potentially affect the activities of the companies. Identifying risk factors raises awareness about the risks associated with behaviours and increases knowledge about which risk factors should be handled with priority (Mikes, 2011). Gordon et al.(2009) found that companies with higher standard of risk analysis and management are more effective. The two approaches that can offer critical learning about risks are qualitative and quantitative. Many development organizations combine the two approaches in order to define, analyse and present the threats they can face (Baker et al., 1998). Assessment of risk variables is necessary in order to contrast risks and when calculated in terms of money (Collier). Qualitative methods, similar to an investigation of the root cause, are ideal for determining explanations for risks. The need for a plan to think about the risks depends on the situation being clear. Risk assessment in highway planning projects includes outstanding risk-measuring devices (Taroun et al., 2011). The basic explanation for exceptional estimation apparatuses is the uniqueness of any construction venture; for instance, only here and there are any verifiable details available.

II. STATEMENT OF PROBLEM AND RESEARCH OBJECTIVES

Risks in highway project construction are increasing its cost and completion time. Risks also affect the quality of highway construction work, thus risks affecting the objectives and project success factors in the construction of highway projects. To save the project from unnecessary cost and time overrun, the risks associated with the construction of highway projects need to be analysed. In this research, we use ISO 31000:2018 for addressing the risk assessment.

This research focuses on the risk management in highway project construction with a focus on risk identification, risk assessment, risk allocation and risk response. The following research objectives were targeted at achieving

A. Identification of risk events related to highway construction projects through literature review and discussion with experts in highway construction.
B. Questionnaire survey to obtain information on the occurrence of risk, risk consequence on cost, time and quality of road construction projects, risk detectability, risk vulnerability, risk allocation and risk responses.
C. To propose a fuzzy model using MATLAB Computer Software for Ranking of risks.
D. Identification of most important risk factors.

E. Allocation of risk to client or contractor or concessionaire or sharing among them.
F. Identification of Ranking of each risk. All the above target achieve with the help of ISO 31000:2018. That is Risk assessment is taken with the help of ISO 31000:2018. Risk assessment is the overall process of Risk identification, Risk analysis and Risk evaluation.

III. ISO 31000:2018

ISO 31000:2018 provides a set of principles, guidelines for the design, implementation of a risk management framework and recommendations for the application of a risk management process. The risk management process as described in ISO 31000 can be applied to any activity, including decision-making at all levels.

The difference between the terms risk management framework and risk management process is described by ISO as in the following:

Risk management framework - set of components that provide the foundations and organizational arrangements for designing, implementing, mentoring, reviewing and continually improving risk management throughout the organization.

Risk management process - systematic application of management policies, procedures and practices to the activities of communication, consulting, establishing the context, and identifying, analyzing, evaluating, treating, monitoring and reviewing risk.

In other words, what ISO 31000 does is that it formalizes risk management practices, and this approach is intended to facilitate broader adoption by companies who require an enterprise risk management standard that accommodates multiple 'silo-centric' management systems.

The scope of this approach to risk management is to enable all strategic, management and operational tasks of an organization throughout projects, functions, and processes to be aligned to a common set of risk management objectives.

Accordingly, ISO 31000 is intended for a broad stakeholder group including:

A. Executive level stakeholders
B. Appointment holders in the enterprise risk management group
C. Risk analysts and management officers
D. Line managers and project managers
E. Compliance and internal auditors
F. Independent practitioners.

IV. FUZZY LOGIC

Fuzzy Logic Fuzzy logic had however been studied since the 1920s, as infinite valued logic notably by Lukasiewicz and Tarski. After 45 years Lotfi Zadeh introduced the term fuzzy logic with 1965 proposal of fuzzy set theory.

Fuzzy logic is used in those research areas where one can't conduct large number of experiment as done in probability theory to construct PDF, NDF etc. Using fuzzy logic, assessments of the problem can be elicited from experts in the form of linguistic terms such as "very low", "low", "medium", "high", "very high".

Fuzzy logic has ability to assign membership values $\mu(x)$ expressing the degree (0 for fully unfit to fully fit 1) to which a certain value of a variable fits a linguistic concept. Membership function defines how each point in the input space is mapped to degree of membership.

V. RESEARCH METHODOLOGY

Traditionally risk was calculated on the basis of Risk Occurrence and Risk Consequence. However, as per ISO31000:2018 numerical Value of risk depend upon Risk Occurrence, Risk Consequence, Risk Detectability and Risk Vulnerability.

Risk Managements steps as per ISO31000:2018

A. Risk Identification
B. Risk Rating
C. Risk Evaluation
D. Risk Response and Allocation

Following linguistics variables were defined on the basis of perspective of project team.

Table: 1 Linguistic Definition of Risk Occurrence

Linguistic Term	Risk Occurrence
Very High (VH)	>70% chance. Risk event will surely occur.
High (H)	50 to 70% chance. Risk event is expected to occur.
Medium (M)	30 to 50% chance. Risk event may occur.
Low (L)	10 to 30% chance. Risk event is implausible to occur.
Very Low (VL)	<10% chance. Risk event is highly implausible to occur.

Table: 2 Linguistic Definition of Risk Consequence

Linguistic term	Risk Consequence
Very High (VH)	Unexpected Increment in cost and duration of project
High (H)	Expected increment in cost and duration of project
Medium (M)	Moderately expected increment in cost and duration of project
Low (L)	Highly expected increment in cost and duration of project
Very Low (VL)	Very high expected increment in duration and cost of project

Table: 3 Linguistic Definition of Risk Detectability

Linguistic term	Risk Detectability
Very High (VH)	Project team is unable to identify risk event response strategy to detect risk event and controlling its consequences.
High (H)	Project team is able to identify risk event response strategy with little chance to detect risk event and controlling its consequences.
Medium (M)	Project team is able to identify risk event response strategy with medium chance to detect risk event and controlling its consequences.
Low (L)	Project team is able to identify risk event response strategy with big chance to detect risk event and controlling its consequences.
Very Low (VL)	Project team is able to identify risk event response strategy with very high chance to detect risk event and controlling its consequences effectively.

Table: 4 Linguistic Definition of Risk Vulnerability

Linguistic term	Risk Vulnerability
Very High (VH)	Project team is unable to fulfill the loss due to risk
High (H)	Project team may be unable to fulfill the loss due to risk
Medium (M)	Project team is moderately unable to fulfill the loss due to risk
Low (L)	Project team is able to fulfill the loss due to risk
Very Low (VL)	Project team is Highly able to fulfill the loss due to risk

Table 5. Crisp Rating used in Questionnaire

Linguistic term	Crisp Rating
Very Low (VL)	1
Low (L)	2
Medium (M)	3
High (H)	4
Very High (VH)	5

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Total 55 risk factors is recognized through literature review and discussions with experts in highway construction. After the risk factors were identified, a questionnaire form was prepared in the following format as given in Table: 6. It was determined to collect information on the occurrence, consequences, detectability and vulnerability of highway construction risk factors.
Data collected on above questionnaire was taken as input for fuzzy MATLAB model and value of Risk Index was calculated by using model presented in figure 1.

Table 6. Identified Risk Factors

Risk No.	Risk Factor	RO	RC	RD	RV	Risk Allocation	Risk Response
R1	Lack of experience of consultant, contractors or sub-contractors						
R2	Contractor Productivity Issues						
R3	Insufficient availability of time to complete project						
R4	Change in construction scope						
R5	Change of owner of project						
R6	Rework due to errors						
R7	Incomplete or complexity in project team						
R8	Non-reliability in construction work quality						
R9	Design Errors and Omissions						
R10	Uncertainty in horizontal and vertical alignment						
R11	Uncertainty in access requirement						
R12	Issues related to obtaining railway and government Permit						
R13	Change in rules, regulations and policies of government						
R14	Bribe						
R15	Expropriations Risk						
R16	Encroachment Risk						
R17	Obsolete technology						
R18	Inappropriate construction methods						
R19	Delay in preparation of submittals						
R20	Delay in approval of submittals						
R21	Insufficient availability of lands						
R22	Uncertainty in Land acquisition cost and schedule						
R23	Natural Obstructions i.e. hill, river, trees etc.						
R24	Uncertainty in landscaping activities						
R25	Utilities not allocated on times						
R26	Lack of availability of utilities						
R27	Uncertainty in price of utilities						
R28	Unskilled members in organization						
R29	Labour dispute and strike						
R30	Conflict between project related parties						
R31	Reputations of organization in market						
R32	Labour productivity issues						
R33	Poor communication and coordination between project team						
R34	Bankruptcy risk						
R35	Lack of resources						

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R36	Fluctuation in prices of material and equipments						
R37	Quality issues of materials and equipments						
R38	Unanticipated damage during construction						
R39	Failure, damage, fire or theft of material and equipment						
R40	Safety issues i.e. labour injuries						
R41	Poor soil conditions						
R42	Chance of rise in G.W.T						
R43	Unforeseen climate conditions on site location						
R44	Poor drainage facilities on site location						
R45	Existing traffic						
R46	Force Majeure						
R47	Poor site management						
R48	Heritage Issues						
R49	Insufficient availability of fund/money						
R50	Taxes issues						
R51	Conflict in contract document						
R52	Delay in payment						
R53	Inflation Rate						
R54	Environment Impact Assessment Required						
R55	Adverse weather Conditions						

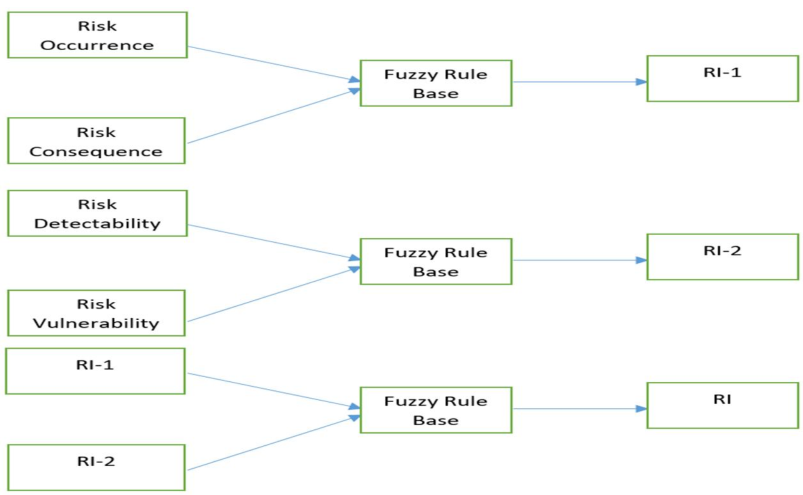

Figure 1. Input-Output model for RI calculation

1) *Sample Fuzzy Rules:* These rules are generated after a deep discussion with Highway Construction Experts.
If RO is L and RC is H then RI is H.

RI	RC					
RO		VL	L	M	H	VH
	VL	VL	VL	L	M	H
	L	VL	L	M	H	H
	M	L	M	M	H	H
	H	M	M	H	VH	VH
	VH	M	M	H	VH	VH

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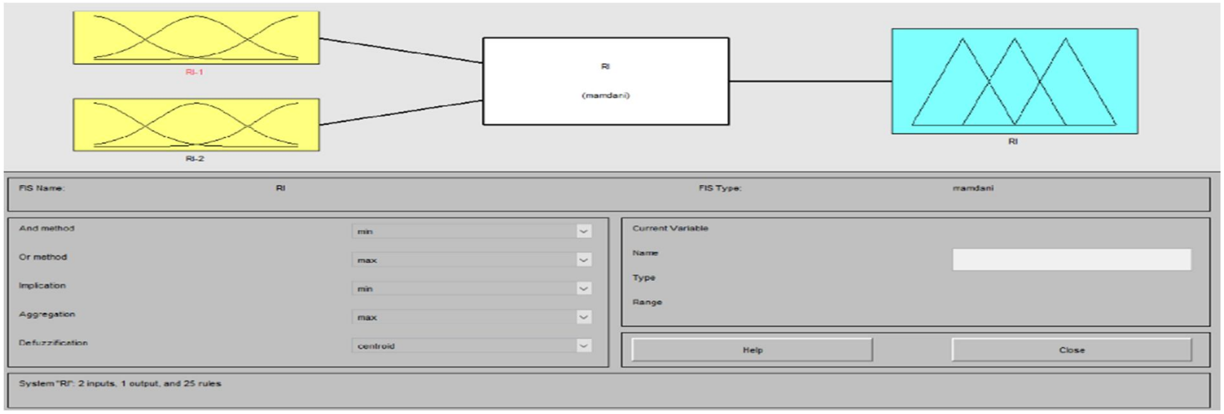

Fig. 2 Fuzzy MATLAB model for Risk Index Calculation

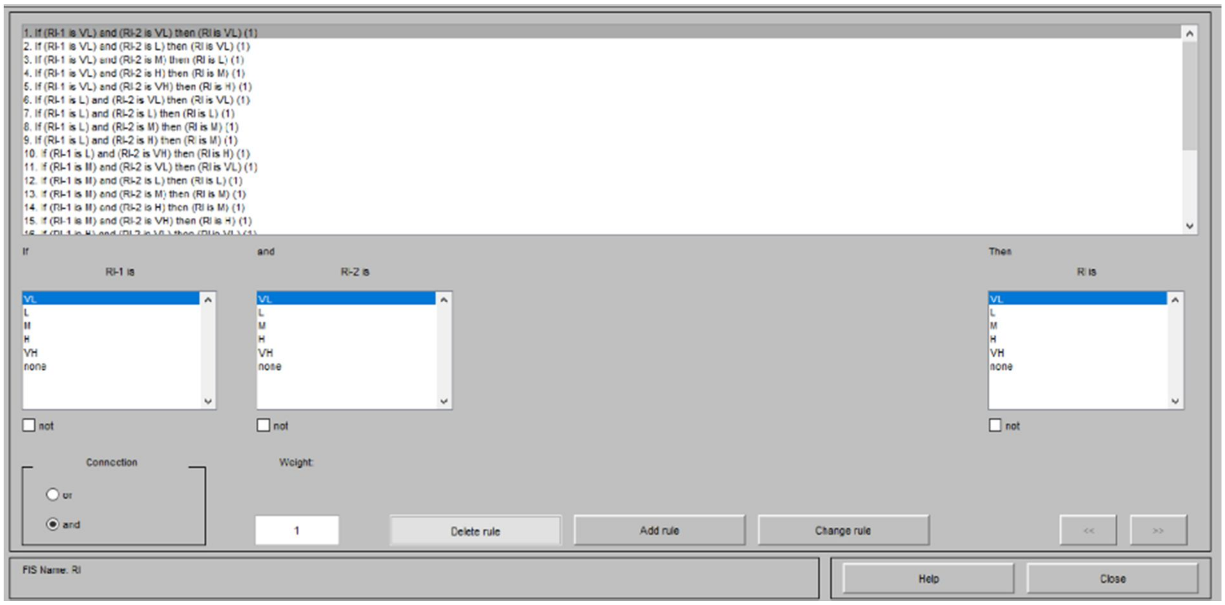

Fig. 3 Fuzzy Rule Base

Table 2. Risk Management table

Risk No.	Rank	Risk Response Strategy	Risk Allocation
R1	43	Mitigate by mentioning minimum experience requirement in NIT form	Client
R2	27	Mitigate by making better communication and coordination b/w project team, Training of Workers & Safety Programs	Contractor
R3	40	Mitigate by 24 hours working through regulating manpower and equipments and machineries	Share
R4	23	Accept the risk or Mitigate by understanding the Project`s vision, l clear estimation & Formalizing the construction project plan	Client
R5	53	Mitigate by legal document	Client/Beneficiary
R6	11	Mitigate by hiring skilled employees and training them	Contractor
R7	36	Mitigate and transfer by hiring reputed & experienced consultancy firm	Contractor
R8	52	Mitigate by conducting proper site investigation and forecasting accurate traffic load or reviewing the design, Transferring to design team	Client
R9	42	Mitigate by hiring experienced and professional design team or Transferring to design team	Client
R10	35	Avoid by proper planning of highway construction route	Client
R11	13	Avoid by making the highway accessible by connecting it to required places	Client
R12	26	Avoid by negotiating the permit holder regularly to reach a final solution within time limit.	Client
R13	30	Accept the risk	Share
R14	28	Accept the risk	Contractor
R15	49	Mitigate by keeping alternate solution	Contractor

R16	46	Accept the risk	Client
R17	37	Avoid by keeping eyes on new upcoming technologies and updating the firm through new technologies	Contractor/ Consultant
R18	20	Avoid by keeping eyes on new upcoming pavement construction methods, pavement materials	Contractor/ Consultant
R19	47	Mitigate by selecting alternate location for keeping work in progress and putting penalties on approval team	Contractor
R20	38	Avoid by taking approval before starting work or mitigate by selecting alternate location for keeping work in progress	Client
R21	3	Avoid by negotiating the land owner regularly to reach a final solution in time limit.	Client
R22	6	Avoid by preparing good Compensation plan to attract land owner.	Client
R23	9	Avoid by getting permit to remove obstructions from concerned department or change the alignment of road	Client
R24	45	Avoid by surveying requirement of landscaping activities before starting highway construction work	Contractor/ Client
R25	55	Mitigate by deciding minimum utilities requirement per day and advance booking of utilities	Contractor
R26	39	Accept the risk	Contractor
R27	51	Avoid by recruiting experienced members in organization	Contractor
R28	14	Avoid or mitigate by providing, required facilities & good wages to labour, bonus & incentives etc.	Contractor
R29	34	Avoid by preparing legal documents or Mitigate by following arbitration process	Share
R30	31	Avoid by hiring skilled labour and training the labour and Mitigate by running motivational programs and bonus Scheme	Contractor
R31	44	Mitigate by conducting regular project execution meeting to enhance flow of information	Contractor
R32	25	Avoid by reducing and accurate estimation of cost of construction & optimizing the revenue	Client
R33	2	Mitigate by proper procurement of resources after doing resources scheduling, updating & allocation	Contractor
R34	22	Avoid by claiming for compensation to client for price Increase	Contractor
R35	54	Avoid by following minimum wages act and launching bonus and incentives scheme, attracting and fixing wages increment interval and rate	Contractor
R36	32	Avoid by testing of materials and equipment before put in use or Transfer to material and equipment supplier	Contractor
R37	10	Mitigate by working carefully under supervision of experienced consultancy	Contractor/ Consultant
R38	5	Avoid by hiring reputed security agencies, maintainer of equipments and machineries	Contractor
R39	16	Mitigate by provision of safety measure, regular safety inspection and appointing safety officers and safety Assistants	Contractor
R40	12	Avoid by improving engineering properties of soil by Stabilizing	Client/ Contractor
R41	19	Mitigate by sealing subsoil, providing underground drainage facilities	Client/ Contractor
R42	1	Accept the risk	Contractor
R43	24	Mitigate by constructing side drain along the road and provide some required slope to drain water	Contractor
R44	18	Accept the risk	Share
R45	33	Mitigate by appointing experienced site manager and assistants and prepare the effective site execution schedule	Contractor
R46	50	Avoid by diverting the alignment of highway	Client
R47	29	Avoid by selecting alternate minerals of similar properties	Contractor
R48	7	Avoid by loan or selecting most suitable financial resource	Client
R49	21	Mitigate by adding all contingencies in contract documents and completing work within time and cost limit	Share
R50	41	Mitigate by hiring reliable and popular third party	Contractor
R51	17	Accept the risk or mitigate by establishing clear time cash flow program	Contractor /Client
R52	48	Accept the risk or mitigate by limiting construction scope and buying some Treasury Inflation Protected Securities	Contractor
R53	15	Mitigate by hiring of a EIA team, Placing of pollution control device(chimney, stakes, pollution units) on site and plant, using higher Bharat Stage equipments	Share
R54	8	Transfer by Insurances and Client should allow EOT to Contractor, and Contractor should restart work	Client/Contractor
R55	4	Accept the risk and Transferring by Insurances and Client should allow EOT to Contractor, and Contractor should restart work immediately	Client/Contractor

VI. CONCLUSION

Risk management process in construction projects is usually applied in planning phase of project. However, at times, project team wishes to apply the risk management process through the execution phase of project. Accordingly, this study provide a complete framework to evaluate, response and allocate the risk in every phase including the execution of highway construction projects. For this purpose, a fuzzy MATLAB based model is developed to evaluate the risk. In developed model, risk index-1 (RI-1) is calculated by taking the risk occurrence (RO) and risk consequences (RC) as input, whereas the risk index-2 (RI-2) is calculated by taking the risk detectability (RD) and risk vulnerability (RV). Then, finally, the risk index (RI) is calculated by taking RI-1 and RI-2 as input. Subsequently, ranking of risk factors is done on the basis of calculated values of RI, RI-1 and RI-2. Risk response and risk allocation strategies are finalized on the basis of suggestions given by project teams.

In order to demonstrate the validity and applicability of proposed model, it is applied to three real case study project. Input data for proposed model is acquired from respective project team, then, ranking of risk factors is done using fuzzy-MATLAB model. Results of case studies illustrate the following potentials of developed model:

A. Identified risk factors are sufficient to be consider in the risk management process of highway construction projects.
B. Proposed fuzzy-MATLAB model is able to handle the uncertainties involved in quantitative analysis of risk factors.
C. Risk response strategies are sufficient to treat the risks associated to highway construction projects.
D. Developed risk allocation plan is appropriate to manage the responsibilities to treat the risks in highway construction projects.
E. Finally, to maximize the profit in construction projects, the proposed model will be beneficial in todays' competitive situation market of construction market.

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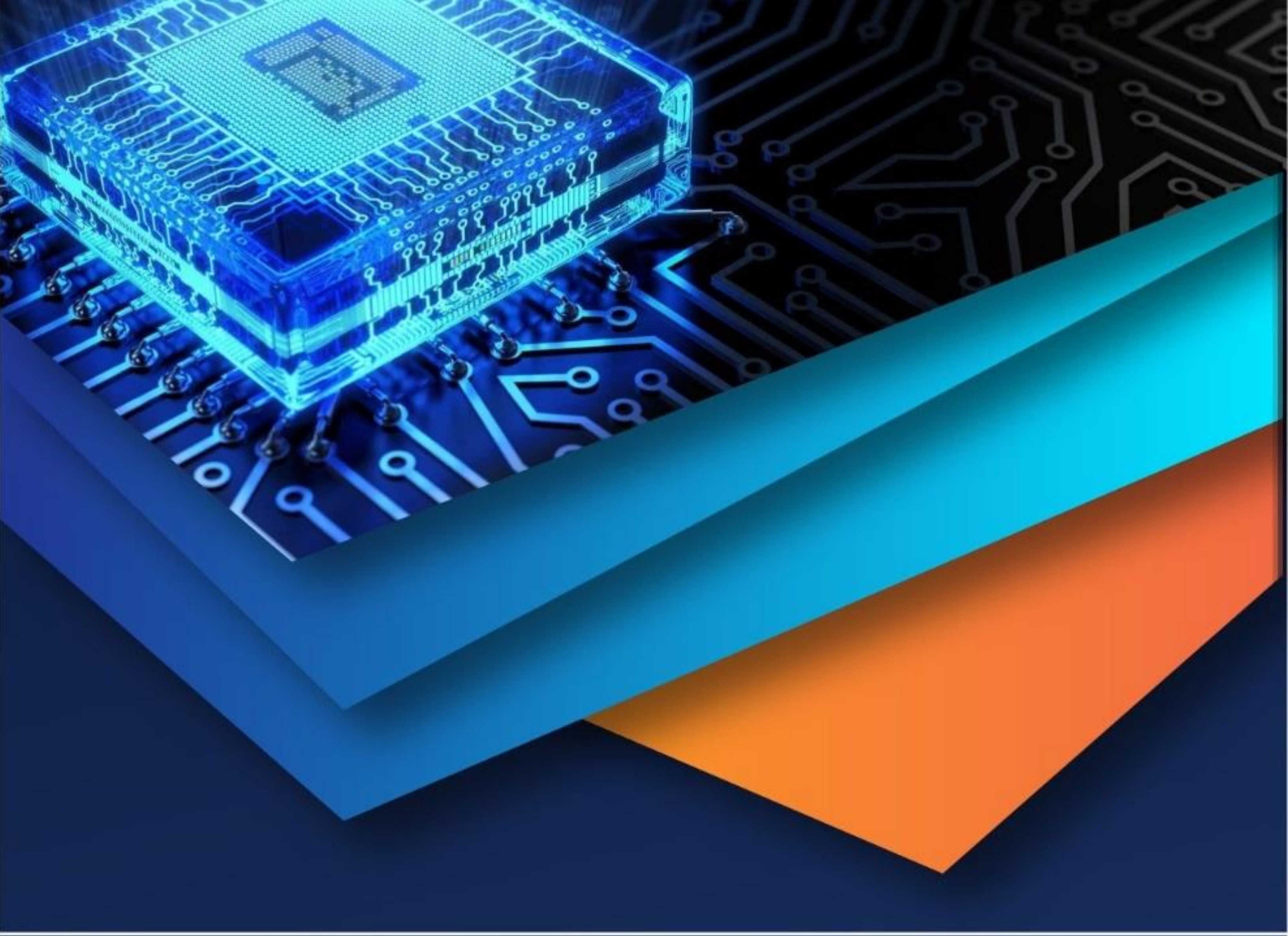

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