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Risk Analysis in Highway Construction Projects Using Failure Mode & Effect Analysis

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Abstract: ***Risks in any construction projects affect the cost, time and quality of work, so it is required to analyze and response the risks before occurring any harm. This research presents a complete framework to identify, assesses, and response the risk events in highway construction projects. Failure Mode & Effect Analysis (FMEA) is a structured technique which is recognized as one of the most suitable technique to analyze risk factors. In this research each risk is considered as failure mode. In FMEA Risks are prioritized on the basis of Risk Priority Number (RPN). RPN is multiplication of occurrence, consequence and detectability of risk. A risk having higher RPN than others means that it requires more attention for responses than others. In this research 48 risk factors are identified by literature review and discussion with highway construction experts. Occurrence, consequence and detectability of each risk factor are elicited from highway construction experts on 5 point scale during questionnaire survey. RPN is calculated after unifying the questionnaire data using Relative Importance Index (RII). This research also proposes a risk allocation plan and risk response strategy to each risk factor.***

Keywords: Highway Construction Projects, Risk Analysis, Failure Mode & Effect Analysis (FMEA), RPN, RII.

I. INTRODUCTION

Objectives of any project are to complete the project within budgeted cost, time and quality as given in specification document. But, risks are the uncertainties which affect the objectives. Highway construction projects require large investment of time, cost and quality but highway construction work involves many types of risks which can play as a threat and might affect the cost, time and quality of work.

Thompson and Perry (1992) concluded that "to complete any project successfully it is necessary to manage the risks effectively before starting project." Failure Mode & Effect Analysis (FMEA) is one of the most accepted technique to analyze risks in any process and product.

FMEA technique was developed by reliability engineers of U.S.A for their army works. But now it is used in several industrial and research fields. In this research each risk is considered as failure mode. In FMEA Risks are prioritized on the basis of Risk Priority Number (RPN).

RPN is multiplication of occurrence, consequence and detectability of risk. In FMEA it is required to understand the meaning of "Failure Mode" & "Effect Analysis".

"Failure modes" means the way, or modes, in which something might fail.

"Effect analysis" refers to studying the consequences of those failures.

Risk has mainly three components, Occurrence (O), Consequence (C) and Detectability(D). RPN is function of O, C & D i.e. RPN = O×C×D

Risk Occurrence (RO) refers to probability of occurrence of risk event.

Risk Consequence (RC) refers to impact of occurred risk on objectives of project.

Risk Detectability (RD) refers to likelihood of discovering and correcting a risk event prior to harm occurrence.

This research also presents a FMEA table which can be considered as concluded part of research. FMEA table shows the Risk Occurrence, Risk Consequence, Risk Detectability, Risk RPN, Rank, Risk Allocation Plan and Risk Response strategy.

In past researches risks in highway construction projects are analyzed by using risk score which depends upon only the occurrence and consequence of risk event, but it is also required to consider the current control on risk event and there is no doubt that Failure Mode & Effect Analysis is one of the most useful technique which analyze the risks beyond occurrence and consequence by considering detectability of risk

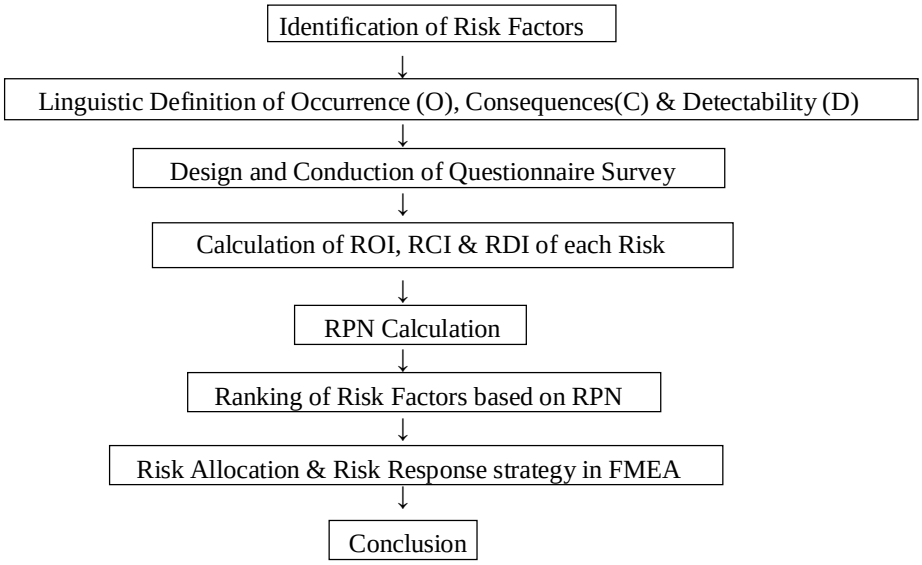
II. OBJECTIVE OF RESEARCH

Objectives of this research are given below-

1) To identify the risks in highway constr7uction through literature review and discussion with highway construction experts.
2) To assess the Occurrence, Consequences and detectability of Risk factors through questionnaire survey to Calculate RPN of each risk factor.
3) To prioritize the risk factors on the basis of their RPN values.
4) To propose a risk allocation plan and risk response strategies for each risk factor.

III. PROPOSED METHODOLOGY

Research Flow



1) Step 1: Identification of risk factors

Total 48 risk factors were identified through literature review and discussion with highway construction experts. A questionnaire form is prepared in following format-

Table: 1 Questionnaire Form

Risk No.	Risk Factor	RO	RC	RD	Risk Allocation	Risk Response
R1	Lack of experience of consultant, contractors					
R2	Lower Contractor Productivity					
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	Expropriations Risk					
R15	Encroachment Risk					
R16	Obsolete technology					
R17	Delay in approval of submittals					
R18	Insufficient availability of lands					
R19	Uncertainty in Land acquisition cost and schedule					
R20	Natural Obstructions i.e. hill, river, trees etc.					
R21	Lack of availability of utilities					
R22	Uncertainty in price of utilities					
R23	Unskilled members in organization					
R24	Labour dispute and strike					
R25	Conflict between project related parties					
R26	Labour productivity issues					
R27	Poor communication and coordination between project team					
R28	Bankruptcy risk					

R29	Lack of resources					
R30	Fluctuation in prices of material and equipments					
R31	Labour wages issues					
R32	Quality issues of materials and equipments					
R33	Unanticipated damage during construction					
R34	Failure, damage, fire or theft of material and equipment					
R35	Safety issues i.e. labour injuries					
R36	Poor soil conditions					
R37	Chance of rise in G.W.T					
R38	Unforeseen climate conditions on site location					
R39	Poor drainage facilities on site location					
R40	Existing traffic					
R41	Force Majeure					
R42	Poor site management					
R43	Heritage Issues					
R44	Mineral mining issues					
R45	Insufficient availability of fund/money					
R46	Conflict in contract document					
R47	Delay in payment					
R48	Adverse weather Conditions					

2) *Step 2:* Linguistic Definition

After identification of risk factors, a meeting was arranged with risk coordinators working on NH-234 (from Etawah to Kannauj, India) to define linguistic terms for each variable. The linguistic term for each variable are "Very High", "High", "Medium", "Low", "Very Low". Meaning of each linguistic term associated to all variable are given below-

Linguistic Definition of Risk Occurrence: Table: 2

Linguistic Term	Risk Occurrence
Very High(VH)	Risk event will occur certainly.
High(H)	Risk event is expected to occur.
Medium(M)	Risk event may occur.
Low(L)	Risk event is unlikely to occur.
Very Low(VL)	Risk event is highly unlikely to occur.

Linguistic Definition of Risk Consequence: Table: 3

Linguistic term	Risk Consequence
Very High(VH)	Objectives does not meet business expectations
High(H)	Objectives are unacceptable to project sponsor
Medium(M)	Major part of objectives are unaffected
Low(L)	Few part of objectives are Affected
Very Low(VL)	Objectives degradation is not noticeable

Linguistic Definition of Risk Detectability: Table: 4

Linguistic term	Risk Detectability
Very High(VH)	Very Low probability of discovering and correcting a risk event prior to harm occurrence
High(H)	Low probability of discovering and correcting a risk event prior to harm occurrence
Medium(M)	Medium probability of discovering and correcting a risk event prior to harm occurrence
Low(L)	High probability of discovering and correcting a risk event prior to harm occurrence
Very Low(VL)	Very High probability of discovering and correcting a risk event prior to harm occurrence

Crisp Rating used in questionnaire: Table: 5

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

Note: During Questionnaire survey, experts were also asked to whom risk should be allocated and which type of response is required against risk.

3) Step 3: Questionnaire Survey

Risk assessment is done through Questionnaire survey. Total 39 questionnaire forms in above format (Table:1) were filled by highway construction experts. Respondent profile is given in Table: 6

Respondent Profile: Table: 6

Respondent	Average Experience	Average cost of completion of project	Average time of completion of project
13 Contractors	18.375 years	547 Cr.	32 Months
13 Clients	19 years	498 Cr.	29 Months
13 Consultants	16.620 years	623 Cr.	36 Months
39 Overall	18 years	556 Cr.	32.33 Months

After performing questionnaire survey, responses from questionnaire were unified using Relative Importance Index Method which is given by,

$$RII = \frac{\sum w}{A \times N}$$

Where ∑W = Sum of responses i.e. sum of crisp rating of factor given by respondents,
A = Maximum value of crisp rating which is 5, N = No. of respondents
As per RII concept ROI, RCI & RDI of each risk factor is calculated using following formulas,

$$\text{Risk Occurrence Index (ROI)} = \frac{\sum w}{A \times N}$$

$$\text{Risk Consequence Index (RCI)} = \frac{\sum w}{A \times N}$$

$$\text{Risk Detectability Index (RDI)} = \frac{\sum w}{A \times N}$$

4) Step 4: RPN Calculation

Risk Priority Number (RPN) is multiplication of Occurrence, Consequence and Detectability of Risk. In this research ROI, RCI and RDI are calculated using relative importance index formula. Values of ROI, RCI and RDI are less than one, so the multiplication of ROI, RCI and RDI will be in decimal. To understand and compare the RPN of different-different risk events, resulted multiplication of ROI, RCI, RDI is multiplied by 100. Thus proposed formula to calculate RPN is-

$$\mathbf{RPN = ROI \times RCI \times RDI \times 100} \quad \text{……eq.1}$$

5) Step 5: Ranking of Risk Factors

After calculating RPN of each risk factor using eq.1, Ranking of Risk Factors was done on the basis of Risk Priority Number (RPN) of Risk Factors. ***Higher the RPN, Higher the Risk,*** Thus Ranking of Risk Factors is done as per decreasing order of RPN in such a way that the rank of maximum RPN is one.

6) Step 6: Risk Response Plan and Risk Response Strategies

During Questionnaire survey Experts were also asked to whom risk should be allocated. From Questionnaire it was concluded that risk should be allocated to either Client or Consultant or Contractor.
There are four risk response strategies which are commonly accepted-

a) Risk Avoidance refers to reducing the probability of occurrence of risk to zero by some changes in actual workplan.
b) Risk Mitigation refers to reducing the consequences or impact of risk on objectives of project.
c) Risk Transfer refers to shifting the responsibility of bearing the risk's consequences to third party e.g. insurance policies.
d) Risk Acceptance refers to dealing with risk's consequences directly through planning the time and cost contingencies to response the risk.

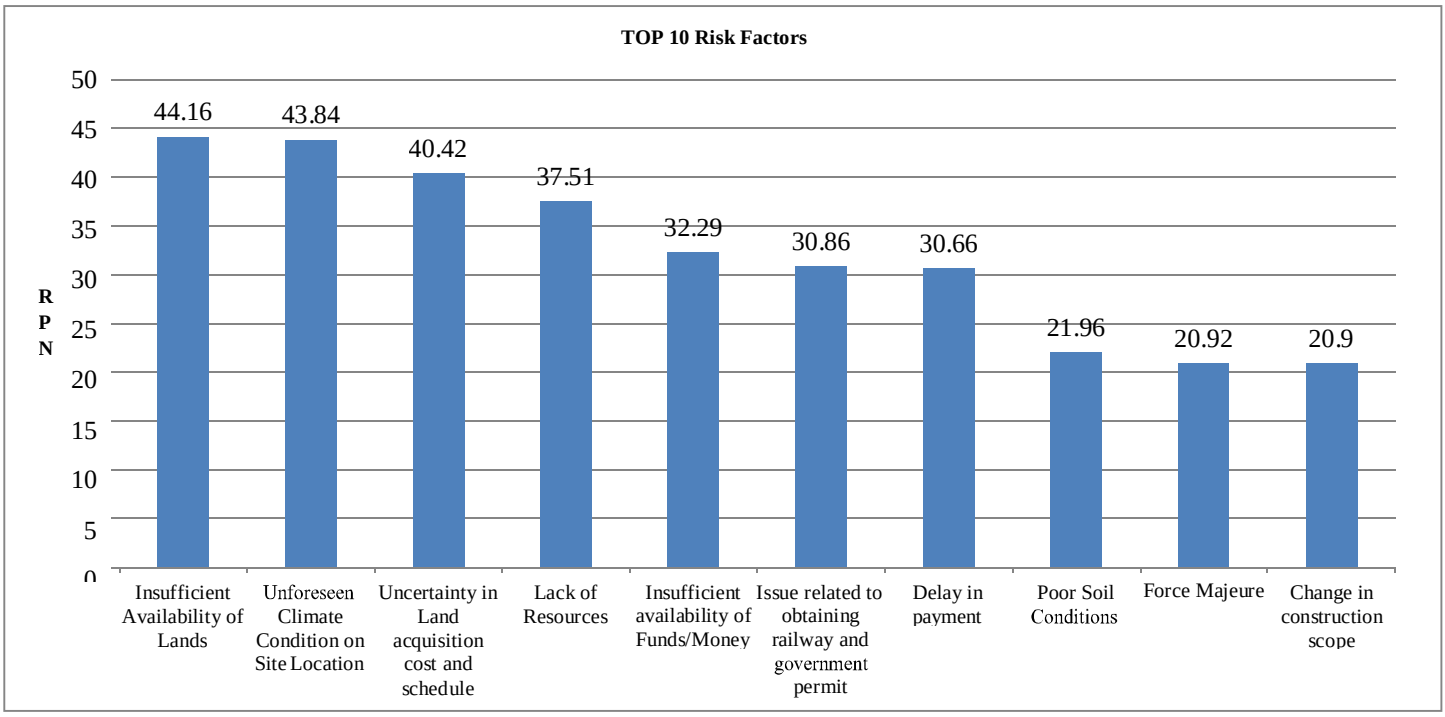
Risk Occurrence Index (ROI), Risk Consequence Index (RCI) and Risk Detectability Index (RDI), Risk Priority Number (RPN), Rank, Risk Allocation Plan and Risk Response Strategy of each risk factor are given in FMEA Table: 7, which can be considered as concluded part of Research.

Table: 7 – FMEA Table

Risk No.	Failure Mode	ROI	RCI	RDI	RPN	Rank	Risk Allocation	Risk Response
R18	Insufficient Availability of Lands	.883	.660	.675	44.16	1	Client	Avoid
R38	Unforeseen Climate Condition on Site Location	.641	.760	.900	43.84	2	Contractor	Accept
R19	Uncertainty in Land acquisition cost and schedule	.875	.616	.750	40.42	3	Client	Avoid
R29	Lack of Resources	.750	.675	.741	37.51	4	Contractor	Mitigate
R45	Insufficient availability of Funds/Money	.550	.641	.916	32.29	5	Client	Avoid
R12	Issue related to obtaining railway and government permit	.808	.675	.566	30.86	6	Client	Avoid
R47	Delay in payment	.633	.625	.775	30.66	7	Client	Accept
R36	Poor Soil Conditions	.708	.525	.591	21.96	8	Client	Avoid
R41	Force Majeure	.558	.625	.600	20.92	9	Contractor	Accept
R4	Change in construction scope	.536	.600	.650	20.90	10	Client	Mitigate
R20	Natural Obstructions i.e. hill, river, trees etc.	.458	.588	.741	19.95	11	Client	Avoid
R33	Unanticipated damage during construction	.600	.416	.750	18.72	12	Contractor	Mitigate
R35	Safety issues i.e. labour injuries	.491	.550	.658	17.76	13	Contractor	Mitigate
R6	Rework due to errors	.525	.483	.683	17.31	14	Contractor	Mitigate
R34	Failure, Damage, fire or theft of material and equipment	.550	.608	.466	15.58	15	Contractor	Avoid
R24	Labour Dispute and Strike	.408	.591	.633	15.26	16	Contractor	Mitigate
R11	Uncertainty in access requirement	.466	.575	.566	15.16	17	Client	Avoid
R39	Poor drainage facilities on site location	.500	.408	.741	15.11	18	Contractor	Mitigate
R30	Fluctuation in prices of material and equipment	.333	.608	.741	15	19	Contractor	Mitigate
R37	Chance of rise in Ground Water Table	.425	.625	.550	14.60	20	Contractor	Mitigate
R46	Conflict in contract document	.466	.500	.625	14.56	21	Contractor	Mitigate
R2	Lower Contractor productivity	.466	.516	.558	13.41	22	Contractor	Mitigate
R26	Labour productivity issue	.483	.550	.491	13.04	23	Contractor	Mitigate
R42	Poor site management	.506	.450	.533	12.13	24	Contractor	Mitigate
R48	Adverse Weather Conditions	.483	.391	.600	11.33	25	Contractor	Accept
R32	Quality issue of materials and equipments	.400	.650	.433	11.25	26	Consultant	Avoid
R25	Conflict between project related parties	.450	.400	.616	11.08	27	Contractor	Mitigate
R10	Uncertainty in horizontal and vertical alignment	.516	.425	.500	10.96	28	Client	Avoid
R44	Mineral Mining issues	.300	.491	.741	10.91	29	Contractor	Mitigate
R22	Uncertainty in price of utilities	.408	.430	.591	10.36	30	Contractor	Mitigate
R3	Insufficient availability of time to complete project	.316	.475	.683	10.25	31	Contractor	Mitigate
R9	Design errors and omission	.408	.500	.491	10.01	32	Consultant	Avoid
R28	Bankruptcy risk	.258	.500	.766	9.88	33	Contractor	Avoid
R13	Change in rules, regulations and policies of government	.491	.366	.550	9.88	34	Client	Accept
R27	Poor communication/coordination between project team	.483	.475	.425	9.75	35	Contractor	Mitigate
R1	Lack of experience of consultant, contractors	.350	.616	.250	9.16	36	Client	Avoid
R8	Non-reliability in construction work quality	.575	.316	.500	9.08	37	Consultant	Mitigate

R15	Encroachment Risk	.300	.480	.591	8.51	38	Client	Avoid
R17	Delay in approval of submittals	.608	.508	.266	8.21	39	Client	Mitigate
R16	Obsolete technology	.291	.375	.725	7.91	40	Contractor	Mitigate
R31	Labour Wages issues	.400	.383	.508	7.78	41	Contractor	Mitigate

R40	Existing Traffic	.633	.325	.375	7.71	42	Client	Avoid
R23	Unskilled member in organization	.383	.533	.358	7.30	43	Contractor	Mitigate
R21	Lack of availability of utilities	.416	.408	.416	7.06	44	Contractor	Mitigate
R43	Heritage issues	.266	.383	.691	7.03	45	Client	Avoid
R5	Change of owner of project	.225	.447	.675	6.78	46	Contractor	Mitigate
R7	Incomplete or complexity in project team	.391	.458	.308	5.51	47	Contractor	Mitigate
R14	Expropriations Risk	.291	.358	.458	4.77	48	Contractor	Mitigate



IV. CONCLUSION

Failure Mode & Effect Analysis (FMEA) is one of the most accepted risk analysis technique which analyzes the risks beyond occurrence and consequence of risks because FMEA also consider the current control on risk or detectability of risk event as third parameter. During research it was observed that questionnaire survey through personal interview is the best method to collect information about risk occurrence, risk consequence, risk detectability, risk allocation and risk response. As per conclusion insufficient availability of land was found to be most important risk factor in highway construction. So it is clear that before staring highway construction, it is required to acquire the required land for highway construction. Unforeseen climate conditions is second and uncertainty in land acquisition cost and schedule is third most important risk factors which affect the objectives of highway construction. FMEA table was designed in the last step of research which shows not only the ROI, RCI, RDI, RPN, and Rank of risk factor but also to whom risk should be allocated and which type of response should be given to each risk factor. In this research it was conclude that risk should be allocated to either clients or contractors or consultants related to project. It is clear from FMEA table that about 90% risks are allocated to contractors, so contractors are the most risks affected project related parties. Risk

response strategies are last but most important part of risk analysis. Four risk response strategies were found most suitable to response the risks which are: 1. Risk Avoidance 2. Risk Mitigation 3. Risk Transfer 4. Risk Acceptance. Response to each risk is given in FMEA Table.

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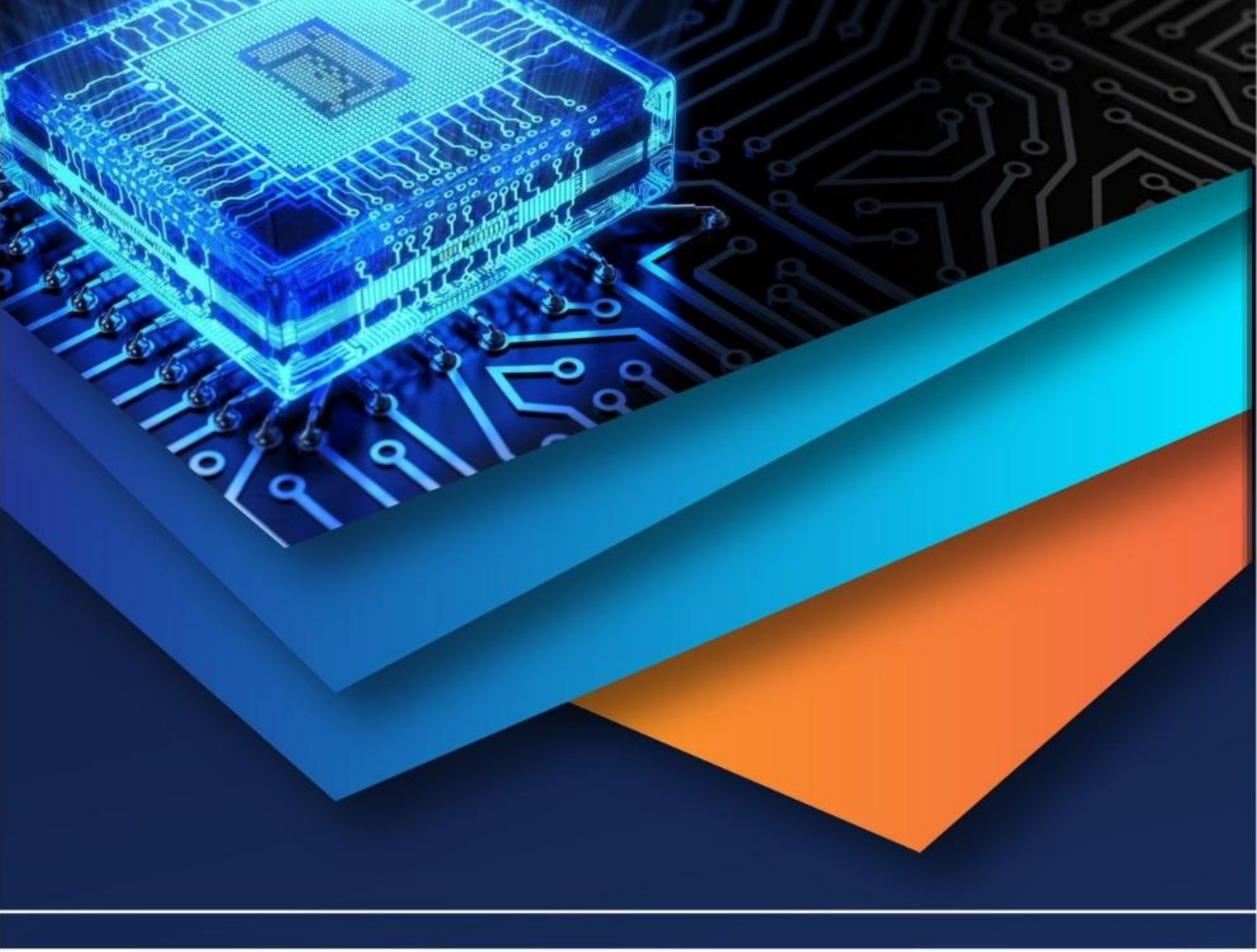

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