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Analysis of Flexible Pavement using IITPAVE Software and Economic Analysis of the Project using HDM-4 Software

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Abstract: ***Road transport plays a vital role in social, economic and industrial development of the country. Roads are used by different vehicle class which results in failure of the pavement due to early deterioration. The failure of bitumen pavement is due to fatigue cracking and rutting deformation. This paved a way for developing the software like IITPAVE which determines the stress and strains values at critical location at different layer of pavement. This project aims at collection of data related to traffic studies and subgrade soil CBR values from the field and designing the flexible pavement as per the guidelines of IRC: 37-2012. Later it is analyzed using the IITPAVE Software to check whether it satisfies the specific requirements.***
An international studies have been carried out by World Bank to extend the scope of HDM-3 Model and to provide an organized system approach to the road management with adaptable and user-friendly software tools. This has resulted in development of new set of Highway Development and Management tools referred as HDM-4 Software by incorporating various new features to work all around the world with any environmental and engineering situations. This project briefly describes the use of HDM-4 for project analysis of National Highway NH-234 of length 56.53km. The HDM-4 tool collects the data related to existing road condition, traffic volume, axle surveys etc. to predict the road deterioration. HDM-4 simulates the use of best alternatives based on the Economic Internal Rate of Return (EIRR) and Economic Net Present Value (ENPV) values
Keywords: fatigue, rutting, IITPAVE, world bank, HDM-4 software.

I. INTRODUCTION

The design of flexible pavement mainly depends on strength and CBR value of the subgrade soil. The pavement design depends on various factors like wheel load, subgrade soil properties, climatic factors, stress distribution characteristics of pavement materials and environmental factors. Pavements are constructed as per IRC guidelines. The main reason for failure of bitumen pavement is due to excessive strain and deformation at critical locations in the pavement.
The objective of this study is to design and evaluate the performance of fatigue and rutting performance of flexible pavements using IITPAVE Software. HDM-4 is a computer software for highways designed by the World Bank. The Highway Development and Management -4 (HDM-4) software is a decision making tool for checking the engineering and economic viability of investments in the road projects. It also provides a powerful system for the analysis of road management and selection of alternatives based on Economic Net Present Value (ENPV) and Economic Internal Rate of Return (EIRR) values.

A. Software Available For Pavement Analysis

1) *IIT PAVE:* IIT PAVE software is an improved version of FPAVE which is developed by research scheme R-56 of MORTH. This is a multilayer analysis programmer used for design, analysis of the flexible or bitumen pavement using IRC: 37-2012 guidelines. In this software we enter thickness of pavement layers, loads applied over the surface of pavement, tire pressure, spacing between the wheels and Poisson´s ratio as inputs. After running the software actual horizontal tensile strain and vertical compressive strains at critical locations of the pavement are obtained as output.
2) *KEN PAVE:* The KENPAVE software is an elastic multilayer system designed by Huang (1993) at university of Kentucky. KENLAYER is a part of KENPAVE used for analyzing the multilayered flexible pavements which has no joints and also rigid pavements such as PCC. The backbone of KENLAYER is that it provides an answer for an elastic multi-layer pavement system under a critical loaded area. This software can be applied to pavement layers carrying vehicles of single, dual, dual tandem or dual tridem wheel assembly along the road where every layer behaves in a different way like linear elastic, non linear elastic and visco elastic.

B. Objectives

1) Traffic Analysis by using collected traffic volume count data by adopting suitable PCU values.

2) Pavement design based on average daily traffic as per the IRC: 37 -2012 guidelines and analyzing pavement in IITPAVE software.

3) Economic analysis of the project using HDM – IV (version 1.3) software.

II. LITERATURE REVIEWS

A. Harish G R (4) (2017), "Analysis of Flexible Pavements Design Using IIT PAVE", Imperial Journal of Interdisciplinary Research (IJIR), Vol-3, Issue-6, 2017, ISSN 2454-1362.

This paper studies the design of flexible pavement by using cementitious materials for base and sub-base layers for crack relief and cementitious base and sub-base with SAMI (Stress Absorbing Membrane Interface) as per the guidelines of IRC: 37-2012 codebook and later the same pavement is analyzed in the IIT PAVE software. IIT PAVE is the multi-layer analysis programmer used for analysis of flexible pavement and to determine the stresses and strains at critical locations of the pavement. In this case the road stretch is selected around Bangalore and engineering properties of subgrade soil has been studied. From their study it is concluded that the pavement which is designed by using cementitious base and sub-base with SAMI will give better serviceability because of substantial reduction in strains and thickness, and also it is cost effective compared to other pavement materials.

B. Komershetty Gouthami, Dr KSR Murthy, D. Sandya Rani [7] (2017), "Flexible pavement design and Comparison of alternative Pavements using IRC 37-2012 IIT PAVE", International journal for scientific Research and Development, vol-5, Issue-6, 2017, ISSN: 2321-0613.

This paper deals in studying the life cycle cost of different pavement compositions. For this purpose, they have collected the information associated to vehicular traffic studies, axle load survey and sub-grade CBR values of a selected road. The project road considered for study is Solapur to Sangareddy section of NH-9. From the obtained data, the design of flexible pavement is carried out using IRC: 37-2012 guidelines.

Later a roadway is analyzed in IIT PAVE software and compared with the pavement which is designed by the alternative materials available in the IRC: 37-2012 with the conventional granular materials.

Based on the results obtained in design of pavement using IRC: 37-2012 and analysis carried out using IIT PAVE software, they have concluded that the alternate pavements with less total pavement thickness can cater the same traffic as that of conventional pavement except the alternate pavement with CTB and GSB.

C. S S Jain, Sanjiv Aggarwal and M Parida (2005) "HDM-4 Pavement Deterioration Models for Indian National Highway Network", Journal of Transportation Engineering, Volume 131 Issue 8 – August 2005.

They attempted to create road deterioration models contained in HDM-4 to model the complex interaction between vehicles, the environment and the pavement structure and surface.

The road deterioration models predict the deterioration of the pavement over a period of time and under traffic. This study attempted to calibrate the HDM4 pavement deterioration models for a National Highway Network located in Uttar Pradesh and Uttaranchal states of India.

The data have been collected regarding to cracking, raveling, potholes and roughness are analyzed and used for calibration of HDM-4 Model. HDM-4 provides a suitable relevance to maintenance and rehabilitation alternatives for a road networks.

D. Dattatraya Thube and Aruna Thube (2013) "Software Development for Calibration of Highway Development and Management Tool (HDM-4) for Local Conditions", International Journal of Structural and Civil Engineering Research, India.

The HDM4 model performs technical and economic appraisals of road projects, different road investment programs and analyzing road network preservation strategies.

Its effectiveness mainly depends on proper calibration to the local conditions. The use of proper calibration factors in HDM-4 model will provide more reliable prediction of pavement deterioration for the road network under considerations. This helps in better assessment of the maintenance and rehabilitation requirements of the pavement.

III. METHODOLOGY

A. General

The flexible pavement is designed by an empirical method, as per the IRC guidelines (IRC: 37-2012) which is based mainly on CBR value of subgrade soil and design charts to determine the total pavement thickness. The design of flexible pavement is done according to IRC: 37-2012 guidelines and it is analyzed in IIT PAVE software. The road selected for this project is Madhugiri – Chikkabbalapur section of NH-234.

A flexible pavement is modelled as an elastic multilayer structure. The mechanistic empirical software called IITPAVE is used to analyze the pavement.

The stress analysis IITPAVE software is used to compute the stresses and strains at critical location of the pavement. Horizontal Tensile strain at the bottom of the bitumen layer and Vertical Compressive strain on the top of the subgrade are considered as the critical parameters to limit cracking and rutting in bituminous and non-bituminous layers.

The allowable tensile and compressive strains at critical location of the pavement are calculated using empirical equations mentioned in IRC: 37-2012 guidelines which is later compared with the actual tensile and compressive strains as computed by IIT PAVE software.

The project analysis application in HDM-4 can be used to carry out economic appraisal for different types of project. It includes widening of roads, new road construction, upgrading, periodic maintenance and rehabilitation works.

The main objective of project level application is to determine the best engineering and economic alternatives for the road sections. The procedure used to carry out project analysis in HDM-4 consists of the following steps:

1) Specify the characteristics of the road sections using Road Network Manager
2) Define the characteristics of the vehicles which uses that road
3) Specify the traffic volumes and growth rates of the vehicles
4) Specify the maintenance and road improvements to be carried out together along with their unit rates.
5) Analyze the project by comparing improved case (with project) with the Base case (without project)
6) Then go to Setup and Run the HDM-4 project analysis application to determine the economic benefits and costs.
7) The reports are generated and if necessary, print the required outputs.
8) Review the reports for which analysis is conducted.

B. Data Collection

Various traffic data are collected like traffic volume count, axle load survey, turning movement counts etc. and also geotechnical investigation tests on subgrade soils like CBR test and Atterberg's tests on the soil along the project road.

1) *Classified Volume Count Surveys:* The classified traffic volume counts were carried out by manually counting the number of vehicles moving on the project road on both directions. The survey was carried out at 2 locations for 24 hours.
2) *Axle Load Survey:* Axle load survey was carried out on normal working days for 24 hours continuously along the project road. The axle load survey is carried out by using two portable weighing pads to measure the weight of the all axles of vehicles in both the direction. For design of pavement, the vehicles whose gross weight is 30KN (3tonnes) or more is considered.
3) *Intersection Turning Movement Survey:* Manual turning volume counts for 12 hour duration are conducted at the junctions covering both morning and evening peaks to analyze the existing turning movement pattern and to plan the required improvements at the junctions.
4) *Subgrade Soil Investigation:* Approximately 15 kg of subgrade soil sample from each test pit is collected along the existing road and various tests like Field Dry Density test, Grain size analysis, Modified Proctor test and 4 days Soaked CBR test are conducted. CBR test is most important test conducted to decide the strength of the soil which decides the total pavement thickness to be provided.

C. Pavement Design and Analysis

The traffic data collected from the traffic volume counts survey is used to determine the number of vehicles plying on that road per day and is used to calculate the design traffic in terms of the cumulative number of standard axles. The pavement is designed as per IRC: 37-2012 guidelines and is analysed using IITPAVE software.

$$N= [365 * A * [(1+r) n-1] * F * D] / r$$

Where,
N = Cumulative number of standard axles to be catered in the design in msa
A = Initial Traffic in year of completion of construction in terms of commercial vehicles per day in CVPD
r = Annual growth rate of commercial vehicles in percentage
n = Design life in years (15 years)
D = Lane Distribution Factor
F = Vehicle Damage Factor
For design purpose, growth rate r = 5% and lane distribution factor D = 0.75

The Initial Traffic in year of completion is estimated using below equation
$A= P (1+r)^x$
Where,
P = Number of commercial vehicles as per last count
x = Number of years between last count and the year of completion of construction
r = Annual growth rate of commercial vehicles in percentage

Table 1: Flexible pavement composition

Section	Design Life	CBR	Initial Traffic	Cumulative number of standard axles	Total Pavement Thickness
Madhugiri - Gauribidanur	15 years	10 %	1261 CVPD	20 MSA	570 mm
Gauribidanur - Chikkaballapur	15 years	10 %	654 CVPD	5 MSA	525 mm

D. Analysis of Flexible pavement using IITPAVE Software

After the pavement is designed as per IRC guidelines it is analyzed in the IITPAVE software to check whether the adopted thickness of each layer of the pavement is sufficient to cater the load and strains developed in the pavement.
The relation between resilient modulus and effective CBR value is given by

M_R (MPa) = 10*CBR for CBR $\leq$ 5
= 17.6*(CBR) $^{0.64}$ for CBR > 5

Where,
M_R
= Resilient modulus of subgrade soil (MPa)
CBR = California Bearing Ratio of subgrade soil is 10%
Resilient modulus of granular layer M_R granular (MPa) = 0.2 x M_R x $h^{0.45}$
Where h = granular layer thickness
Fatigue Model
$N_f = 2.21 * 10^{-4} [1/\varepsilon_t]^{3.89} [1/M_R]^{0.854}$
N_f = Fatigue life,
ε_t = Maximum tensile strain
M_R = Resilient modulus of bituminous layer

Rutting Model
$N_R = 4.1656 * 10^{-8} [1/\varepsilon_v]^{4.5337}$
Where,
N = Cumulative number of standard axles,
ε_v = Vertical strain

Allowable Horizontal tensile strains are calculated by adopting 80% reliability because traffic is less than 30 msa and the actual Vertical compressive strains are computed by IITPAVE software. The corresponding strain values are tabulated in the below table 4.1

E. Analysis of Flexible pavement using HDM-4 Software

Highway Development and Management Tool (HDM-4) is designed to make comparative cost estimate and economic evaluation of different construction and maintenance options. HDM-4 includes the relationships for modelling Road Deterioration (RD) and Road Work Effects (RWE). The cost benefit analysis is carried out by using discounted cash flow (DCF) technique to obtain the economic internal rate of return (EIRR) and economic net present value (ENPV) for the proposed investments linked with the project.

The procedure for project analysis is summarized below

Create the road project to be analyzed by giving it a title and specifying the road to be analyzed.

Define the project by specifying the following

General information of the project like Road Network data, Pavement Condition data, Vehicle fleet data and Traffic Volume data.

Method of analysis

Road sections to be analyzed.

Specify the maintenance and improvement standards to be analyzed for each road section. Set-up and run the analysis.

Generate the reports and print the required outputs.

The various alternatives chosen for the selected road network is tabulated in the below table

Table 2: Various alternatives chosen for the road network

Alternatives	Maintenance Type	Intervention	Surface Thickness (mm)
Base Alternative	Patching	Annually	-
	Resealing	Scheduled at every 5 years	20 PC
	Overlay	Scheduled at every 15 years	30 BC
Alternative 1	Patching	Annually	-
	Resealing	Scheduled at every 5 years	25 SBSD
	Overlay	Scheduled at every 15 years	40 BC
	Partial Widening by 1.5 m		
Alternative 2	Patching	Annually	-
	Resealing	Scheduled at every 5 years	50 DBSD
	Overlay	Scheduled at every 15 years	40 BC
	Partial Widening by 1.5 m		

PC – Premix carpet
SBSD – Single Bituminous Surface Dressing
BC – Bitumen Concrete
DBSD - Double Bituminous Surface Dressing

IV.RESULTS AND DISCUSSION

A. Analysis of pavement by using IIT PAVE software

Before carrying out IITPAVE analysis, the flexible pavement is designed as per IRC: 37-2012 guidelines and the thickness of each layers in pavement structure are determined. In the IIT PAVE software, the elastic modulus, Poisson's ratio, thickness of different layers, wheel load and tyre pressure of a vehicle, radial distance between two tyres are given as input. After entering the input data, click on submit button. After this, click on the run button, this gives the stresses and strains result at different layers by analyzing the input data fed. The strains obtained are compared with the allowable strains. If the actual strains obtained from IITPAVE software is less than the allowable strains obtained from IRC: 37-2012, then the given pavement thickness is said to be safe and satisfied.

Table 3: Horizontal tensile strains

Section	Allowable Strains from IRC:37- 2012	Actual Strains from IIT PAVE	Remark
Madhugiri - Gauribidanur	298.00 x 10^{-6} strains	266.40 x 10^{-6} strains	Safe
Gauribidanur - Chikkaballapur	425.60 x 10^{-6} strains	351.40 x 10^{-6} strains	Safe

Actual horizontal tensile strains are lesser than the Allowable horizontal tensile strains at both the locations. Therefore the assumed pavement thickness is correct and the pavement designed is safe.

Table 4: Vertical compressive *strains*

Section	Allowable Strains from IRC:37- 2012	Actual Strains from IIT PAVE	Remark
Madhugiri - Gauribidanur	577.73 x 10^{-6} strains	345.50 x 10^{-6} strains	Safe
Gauribidanur - Chikkaballapur	784.40 x 10^{-6} strains	500.20 x 10^{-6} strains	Safe

Actual vertical compressive strains are lesser than the Allowable vertical compressive strains at both the locations. Therefore the assumed pavement thickness is correct and the pavement designed is safe.

B. Economic Analysis by HDM-4

The economic evaluation is carried out using HDM-4 software. In this analysis, the 'with project' alternatives of upgrading is compared with the base option 'without project' alternative of maintaining existing road only without any improvements. This is to arrive at the net economic benefits, which consist of reduction in vehicle operation cost and reduction in travel time.

Table 4.5: Results of the Economic Analysis

Alternatives	Economic Net Present Value of Net Benefits at 12 % Discount Rate (Rs in Millions)	Economic Internal Rate of Return in %(EIRR)
Alternative 1	1615.94	27.40 %
Alternative 2	1286.80	24.80 %

V. CONCLUSION

A. The average daily traffic is obtained from the traffic survey data

1) The average traffic volume for section 1 near Arsapura is 4138 PCU

2) The average traffic volume for section 2 near Manchenahalli is 2770 PCU

B. The peak hour junction traffic volume was observed between time 4 pm to 5 pm and the PCU observed are 3299 and 2989 at Gauribidanur and Chikkaballapur junctions.

C. The Flexible pavement is designed by following IRC:37-2012 guidelines and the pavement is analyzed by IIT PAVE software

1) The composition of the pavement for the section 1 (chainage 343+800km to 366+430km) for 20msa is BC = 40mm, DBM = 80mm, WMM = 250mm, GSB = 200mm

2) The allowable tensile strain and actual tensile strain in bituminous layer from IRC: 37-2012 and IIT PAVE for section 1 is 298.00 micro strains and 266.40 micro strains.

3) The allowable compressive strain and actual compressive strain from IRC: 37-2012 and IIT PAVE is 577.73 micro strains and 345.50 micro strains.

4) The composition of the pavement for the section 2 (chainage 366+430km to 400+330 km) for 5 msa is BC = 30mm, DBM = 50mm, WMM = 250mm, GSB = 150mm

5) The allowable tensile strain and actual tensile strain in bituminous layer from IRC: 37-2012 and IIT PAVE for the section 2 is 425.6 micro strains and 344.50 micro strains.

6) The allowable compressive strain and actual compressive strain from IRC: 37-2012 and IIT PAVE is 784.4 micro strains and 488.20 micro strains.

D. The Economic evaluation of project road using HDM-4 software gives results of economic indicators like ENPV = Rs 1615.94 Million and EIRR = 27.40 % for alternative 1 and ENPV = Rs 1286.80 Million and EIRR = 24.80 % for alternative 2 at a discount rate of 12 %. Alternative 1 is selected for this project as it has higher ENPV and EIRR values.

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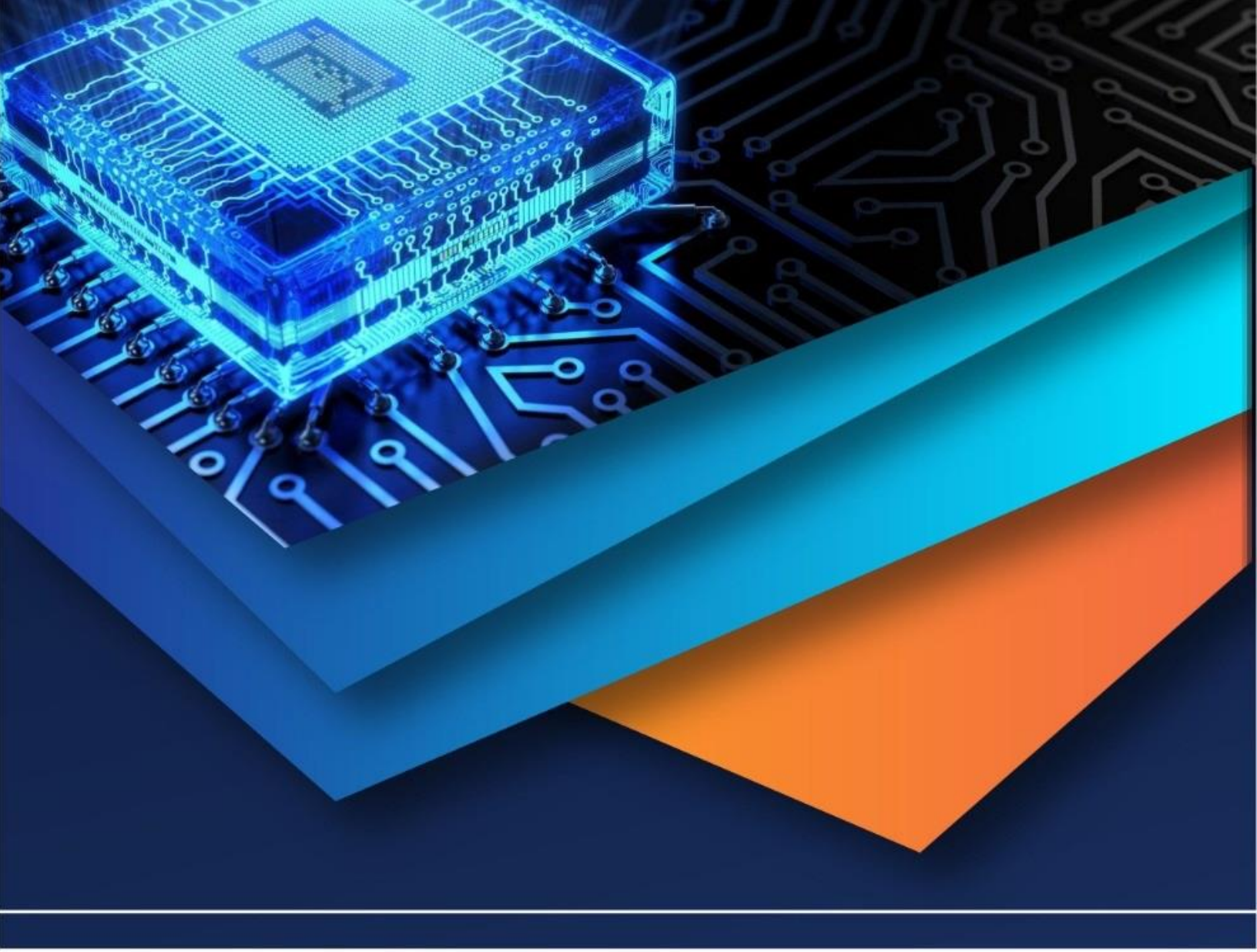

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