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Comprehensive Analysis of Road Surface Irregularities: Cause, Effect and Mitigation Strategies

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Abstract: ***The quality of road facilities is a critical measure of a nation's economic development and overall quality of life. In India, where road transportation is the strength of connectivity, the prevalence of road surface irregularities has emerged as a significant challenge. The present paper aims to systematically examine the multifaceted aspects of road surface irregularities in India. The study begins by providing an overview of the importance of road infrastructure in the Indian context and its insinuations for economic growth and societal well-being. It then delves into the various factors contributing to road surface irregularities, including construction materials, climatic conditions, and traffic volume and maintenance practices. Furthermore, the literature highlights the hostile heightened transportation costs Finally, this paper concludes with insights into the future prospects and challenges in managing effects of road surface irregularities on road users, such as increased accidents, vehicle tear and wear, and road surface irregularities in the Indian context, emphasizing the need for holistic approaches that integrate technological advancements, policy reforms, and sustainable practices to ensure safe and efficient road transportation. This paper serves as a comprehensive examination of the complexities surrounding road surface quality in India and provides valuable insights for policymakers, researchers, and practitioners working towards improving the nation's road infrastructure.***

Keywords: Asphalt, Damage, Irregularities, Pavement, Pothole, Road fatalities.

I. INTRODUCTION

Road accidents have been the leading cause of deaths worldwide with the last three decades seeing a substantial increase in this regard. Road surface irregularities play a crucial role in road safety. Authors are motivated while evaluating the survey regarding road surface irregularities, encounter the statistic of fatalities happening during the active transport due to detreated road [23]. This review aims to delve into the various aspects of road surface irregularities, their impact on vehicles and drivers, and the measures taken to mitigate their effects. The examination covers a wide range of factors, from the types of irregularities to their causes and potential solutions. The review begins by categorizing road surface irregularities into distinct types, including potholes, cracks, bumps, and undulations. Each type is discussed in detail, shedding light on their formation processes and how they manifest. The causes behind these irregularities are explored, ranging from weather conditions and heavy traffic to inadequate road maintenance and construction materials. As per data available in [24], there were 4, 03,100 unfortunate incidences of road accidents during 2021 which claimed 1, 55,622 lives and caused injuries to 3, 71,900 persons. The number of road accidents and fatalities has dropped by 26% and 25% respectively during March-April, 2020 compared to 2019 (Table.1) due to the Movement Control Order (MCO) imposed during the COVID-19 pandemic which resulted in lesser traffic [8]. Again the road fatalities are exponentially rises due to gradual unlocking and phasing out of the containment measures.

	Year	Road Accidents	No. of Injuries	No.of Deaths	No.of Vehicles
0	1995	214.4	266.5	68351	30295
1	2000	308.3	340.2	80118	48857
2	2005	390.4	447.9	98254	66289
3	2010	430.6	470.6	133938	114953
4	2015	464.7	482.4	148707	210023
5	2020	354.8	335.0	133201	295772
6	2021	403.1	371.9	155622	295772

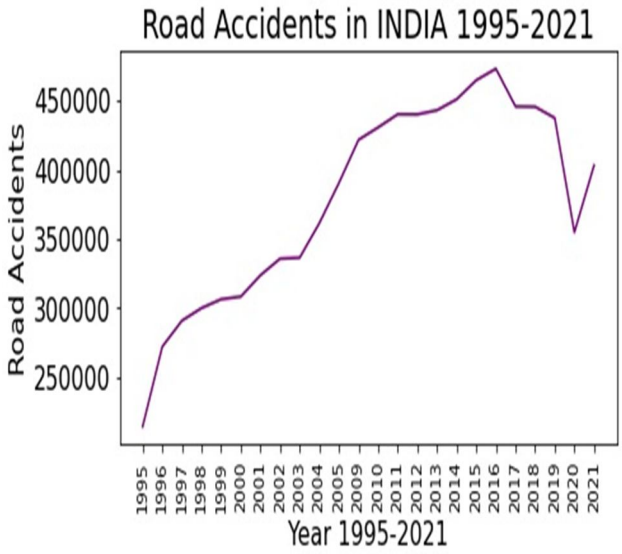
Table 1. Road fatalities according to Report (NCRB-2021) [24]

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The impact of road surface irregularities on vehicles and drivers is a central focus of the review. It delves into the potential damages that vehicles can incur, such as tire and suspension system wear, decreased fuel efficiency, and even accidents due to sudden jolts. A general analysis of data on road traffic accidents shows that with the deterioration of the road surface roughness, the number of road traffic accidents increases [9], hence driver comfort, safety, and overall road quality is also thoroughly analyzed, highlighting the importance of well-maintained road surfaces. The review then explores the technological and engineering advancements aimed at addressing road surface irregularities. It discusses innovations in road construction materials, such as using more durable and flexible materials, as well as techniques like polymer-modified asphalt and concrete. Moreover, it evaluates the effectiveness of road maintenance strategies, such as timely filling of cracks and potholes, as well as the implementation of road smoothness standards. Road surface monitoring also plays a pivotal role in ensuring a comfortable travel experience for road users. Surface roughness must be accorded the highest importance as it directly influences the safety of the users and also increases vehicle operating costs [2]. The International Roughness Index (IRI) is used by highway professionals throughout the world as a standard to quantify road surface roughness. It is an indicator to measure the standard road roughness. Conventional way of measuring IRI involves usage of bump integrator, profilometer and roughometer [3]. Mitigation strategies for minimizing the impact of road surface irregularities are also a significant aspect of the review. The road safety and transport report [24] published in 2021 revealed that India continued to have the most road fatalities in the world, followed by China, a distant second at 63,093 deaths in 2, 12,846 road accidents in 2019 [10]. It outlines the role of government agencies, municipalities, and road authorities in adopting comprehensive road maintenance programs. Additionally, the emergence of smart infrastructure solutions, such as road sensors and predictive maintenance algorithms, is explored, showing promising potential for proactively identifying and addressing irregularities.

Table 2. Rating of Road Pavement according to International Roughness Index (IRI)

Sl No	Parameter	Range of Distress (percent)		
		Good	Fair	Poor
1.	Potholes	Up to 0.5	From 0.5 to 1.0	Above1.0
2.	Patching	Up to 5	From 5 to 20	Above 20
3.	Cracking	Up to 10	From 10 to 20	Above 20
4.	Ravelling	Up to 10	From 10 to 20	Above 20
5.	Pavement Condition Index	4 to 5	2 to 3	1



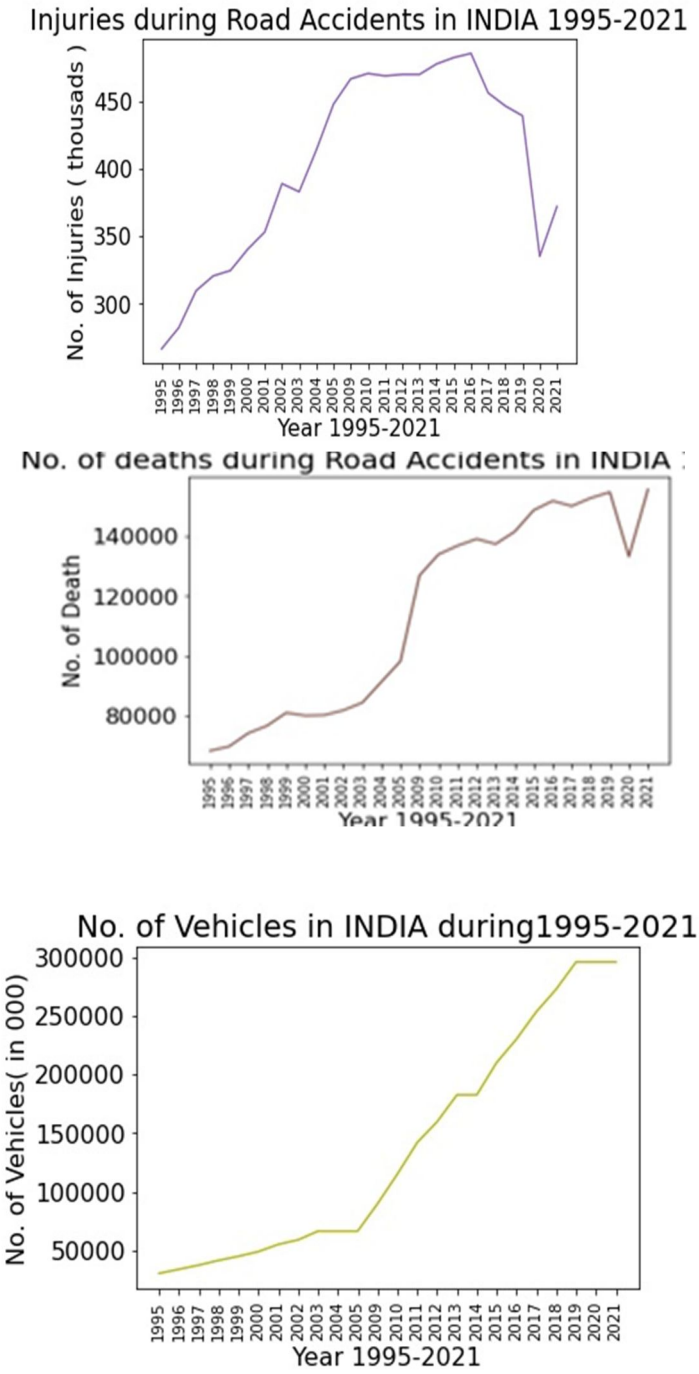


Figure 1. Graphical data depicting road fatalities in India during 1995-2021

II. ROAD SURFACES

Road surfaces [13] refer to the top layer of a roadway, which is designed to provide a safe and durable driving surface for vehicles. The type of road surface used can vary based on factors such as the volume and type of traffic, climate conditions, budget considerations, and the intended lifespan of the road. There are several common types of road surfaces, each with its own characteristics and advantages:

As figure a) shown is a mixture of bitumen binder (a sticky, black substance) and aggregates (such as sand, gravel, and crushed stone) which is most widely used on road surfaces in India. This mixture is equally spread while hot [14] to build a smooth driving surface. It provides good friction and is good for a range of traffic crowd.

But requires regular maintenance and resurfacing because of wear and tear due to heavy traffic and weather conditions. A Mixture of cement, water, and aggregates produced a good quality concrete road surfaces as shown in [Fig. b.] Such surfaces are durable, longer lifespan in comparison with asphalt, as it demands very less frequent maintenance [15]. Initial construction costs for concrete roads are generally high on the contrary, they provide good traction and are less susceptible to damage from heavy loads and temperature fluctuations. Gravel roads are known to be a manually built [Fig. c] pathway simply by spreading a layer of crushed stone or local Murrum [16] on the roadbed. It is very cost-effective to build, but requires regular maintenance to avoid potholes, chatter marks and dust generation [18]. These type of roads are very common in town where it found lower traffic volumes [17].Some roads are constructed using open celled pavers, which involve placing individual units, such as concrete or interlocking bricks [20], to form the road surface. This method allows for intricate designs, but it can be more labor-intensive and expensive. Another kind of road surface known as Chip seal which is built by applying a layer of liquid bitumen on the road surface, covering it with a layer of small aggregate chips as shown in [Fig.e]. Chip seal surfaces are commonly used on lower-traffic-volume roads. Cost effectiveness is the important factor building such type of road surface [19]. It is looks like textured surface, it protect the underlying pavement from water and sunlight. Poriferous surface [Fig. f.] is built to let the water to pass through it, preventing storm water runoff and improving drainage. The road surface performance of both paved and unpaved roads can be improved with the inclusion of geosynthetics [7] [14]. Some road surfaces incorporate recycled materials (fig. g) like reclaimed asphalt pavement [21] or recycled concrete aggregate. This can be environmentally friendly and cost-effective. Sometime special treatments [22] can be applied to road surfaces (fig. h) to improve characteristics like skid resistance, noise reduction, and reflective properties for improved visibility at night.

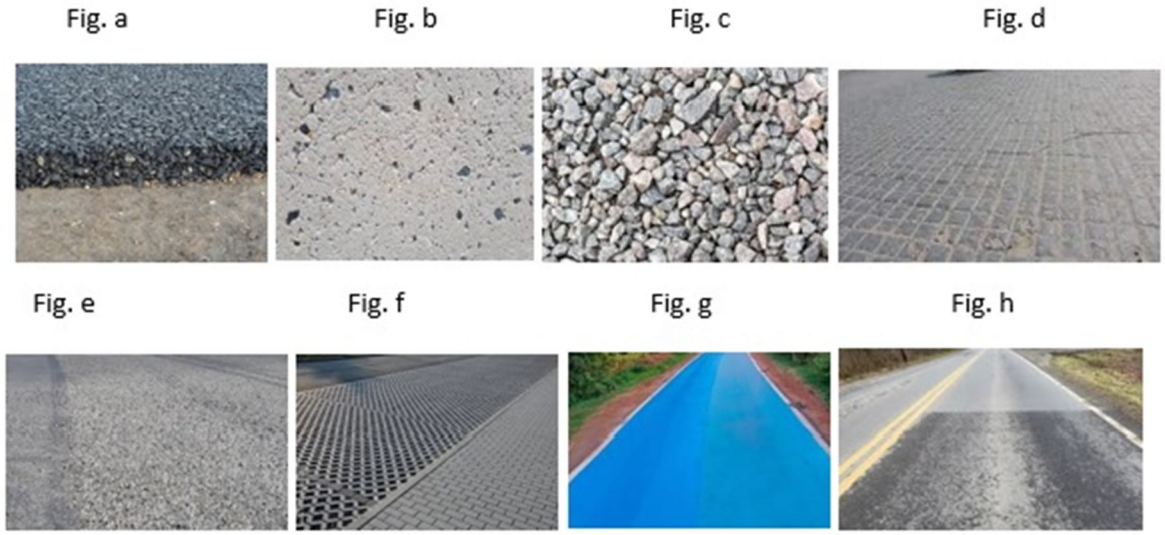


Figure. 2. Types of Road surfaces affecting the National Transport.

All of above road surfaces are a critical component of transportation infrastructure, and their selection depends on a variety of factors. The deterioration of road surface is divided into three factors i.e. personal factor, road environmental factor, and vehicle factor. In relation to traffic accidents, personal, road environmental, and vehicle factors are known to contribute 93%, 34%, and 13% of traffic accident [23]. Proper construction, regular maintenance, and consideration of factors like traffic patterns, climate, and budget are essential to ensure safe and reliable roadways.

III. ROAD SURFACE DAMAGES COUNTS ROAD FATALITIES

Road surface damage is the deviation of a road surface from a true planar surface with characteristic dimensions that affect vehicle dynamics, ride quality, dynamic loads, and pavement drainage. Roughness is primarily related to serviceability, structural deficiencies and road deterioration [6].It has been seen that Irregular road surfaces in rural and urban areas, can significantly contribute to road accidents by creating hazardous conditions that challenge drivers' ability to maintain control two wheelers like motorbikes and scooters because it is most common private transport as it is fast and easy approach to the destination [4]. Potholes are one of the most common distresses in flexible pavement as they can lead to trip and fall accidents and are hence a liability for both public and private properties [1][5].

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A condition of road pavements (surfaces) can also be highly important to influence traffic accidents [12]. To mitigate the risks associated with irregular road surfaces, proper road maintenance, repair, and construction are essential. Adequate signage, warnings, and speed limit adjustments can also help drivers anticipate and navigate these challenges more safely.

Potholes, cracks, uneven surfaces, and debris on the road can reduce traction between the tires and the road. This reduces a driver's ability to control their vehicle, especially in adverse weather conditions. Reduced traction can lead to skidding, loss of control, and potentially result in accidents. Uneven road surfaces can cause sudden jolts and shifts in the vehicle's position. This can lead to a loss of stability, particularly at higher speeds or when making abrupt maneuvers. If a driver is unable to regain control quickly, the vehicle may overturn or collide with other vehicles or obstacles. Damaged road surfaces can increase the distance it takes for a vehicle to come to a complete stop. This is particularly dangerous when drivers need to brake suddenly due to unexpected events. Longer stopping distances can result in rear-end collisions, especially if the driver following behind is unable to stop in time. Rough or damaged road surfaces can impact the effectiveness of braking systems. Brakes may not function optimally on uneven surfaces, reducing their ability to slow down or stop the vehicle effectively. Motorcycles are more susceptible to road surface damage compared to larger vehicles. Potholes, loose gravel, and other road defects can cause motorcycles to lose balance and crash. Riders are more exposed to the environment, making them more vulnerable to injuries or fatalities in such situations. Severely damaged road surfaces can lead to misalignment of vehicle wheels. This affects steering control and stability, potentially causing drivers to lose control of their vehicles. Debris or potholes on the road can lead to sudden swerving or evasive maneuvers by drivers to avoid hitting them. This can result in collisions with other vehicles, objects on the roadside, or even rollovers. Poorly maintained road surfaces, like faded lane markings or damaged signage, can reduce visibility for drivers. This can lead to confusion, lane departure incidents, and increased likelihood of collisions, especially in low-light conditions. Driving on rough or damaged roads requires more effort from drivers to maintain control. This can lead to driver fatigue over long distances, reducing their ability to make quick and effective decisions, increasing the risk of accidents. Poor road conditions can amplify the severity of accidents involving multiple vehicles. A single vehicle losing control due to road surface damage can trigger a chain reaction of collisions involving other vehicles.

IV. MITIGATING STRATEGIES USING MACHINE LEARNING APPROACH

Preventing road accidents due to irregular road surfaces using machine learning involves leveraging data and technology to improve road safety. Deploy sensors, cameras, or drones to collect real-time data on road conditions, including potholes, cracks, and surface irregularities. Nowadays Artificial Intelligence has been arise a state of the art technology which has tremendous potential to revolutionize the entire transportation system and could be use in preventing the road fatalities. It is recommended to use machine learning algorithms to analyze this data and identify hazardous road conditions. One can implement the predictive maintenance models that use historical data to forecast when road surfaces are likely to deteriorate. Schedule maintenance and repairs proactively to address issues before accidents occur. A novel systems can be developed that use machine learning to analyze road condition data and automatically trigger warning signs or signals for drivers and provide real-time alerts to drivers about upcoming road hazards. Automobile sector must come forward to integrate machine learning algorithms into autonomous vehicles to enable them to adapt their driving behavior in real-time based on road conditions. Autonomous vehicles can also share road condition data with other vehicles to enhance safety. The government authorities must prioritize road rehabilitation projects based on historical accident data, traffic patterns, and road condition data. A provision should be made to allocate resources efficiently to address high-risk areas. Academics and research institutes promote the technocrats to develop mobile apps that allow users to report road surface irregularities. Highway traffic management allows to use advanced tech devices equipped with machine learning to validate and prioritize reported issues for quick response.

Integrate weather forecasts into machine learning models to predict how weather conditions might affect road surfaces. Regarding the weather conditions, warnings and recommendations should be convey to drivers accordingly. In this regard Vehicle-to-Infrastructure (V2I) Communication system can be implement that enable vehicles to receive real-time updates on road conditions from roadside infrastructure.so that vehicles can adjust their speed and behavior accordingly. Strategies have to build to encouraging the collaboration between government agencies, transportation companies, and tech companies to share road condition data and develop comprehensive solutions. The advanced feature like Advanced Driver Assistance Systems (ADAS) that use machine learning to assist drivers in navigating irregular road surfaces. These systems can provide steering and braking support when needed.

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To implement these solutions effectively, it's crucial to have access to high-quality road condition data, invest in infrastructure improvements, and ensure collaboration among stakeholders in the transportation industry. Additionally, ongoing monitoring and updating of machine learning models are essential to adapt to changing road conditions and improve road safety continuously.

V. CONCLUSION

In conclusion, road surface damages can compromise the safety of vehicles and their occupants, leading to accidents, injuries, and fatalities. Proper road maintenance, repair, and improvement are crucial for minimizing these risks and ensuring safer roadways for everyone. This comprehensive review provides a deep understanding of road surface irregularities and their far-reaching effects. It effectively analyzes the causes, consequences, and potential solutions related to different types of irregularities. The review underscores the importance of prioritizing road maintenance, using innovative materials, and leveraging technology to create safer and smoother road surfaces. With its well-researched content and insightful analysis, this review serves as an invaluable resource for policymakers, engineers, researchers, and anyone interested in improving road quality and driving experiences.

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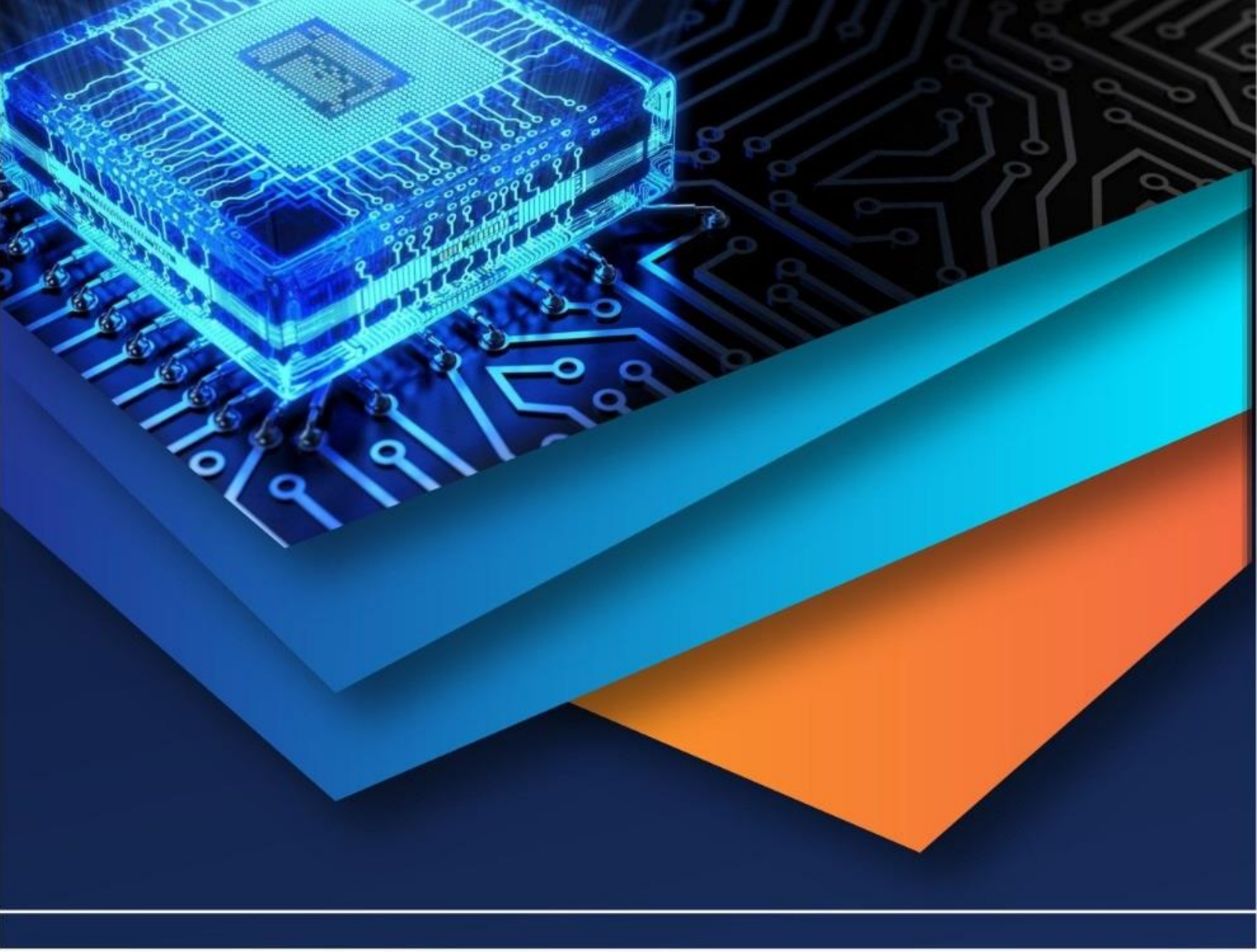
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