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Accident Hotspot Identification and Safety Countermeasure: A Case Study of the Sirhind-Khanna Road Corridor, Punjab, India

Telema J. Thomas[1], Er. Heena Manzoor[2]
[1]PG Research Scholar, Civil Engineering Department, RIMT University, Mandi Gobindgarh, India
[2]Assistant Professor, Civil Engineering Department, RIMT University, Mandi Gobindgarh, India

Abstract: The threat of road traffic accidents remains a significant issue in road safety and transportation especially in such developing nations where these road collisions are becoming serious due to the growing numbers of vehicles on the roads and rapid urbanization in developing cities and towns coupled by inadequate road infrastructure. The present research is centered around the identification and prioritization of the accident hot spots on Sirhin- Khanna Road corridor in the state of Punjab, India, with the help of an integrated multi-method analytical approach. This study used data concerning five years of accidents (2020-2024) gathered by traffic police and highway authorities. The entire corridor length of 20 km was subdivided into equally sized sections of 500 m each for easier detailed analysis. In total six analytical methods were used in the project: Accident Frequency Method, Weighted Severity Index (WSI), Crash Severity Index (CSI), Critical Rate Method, Moving Average Method and Accident Density Method. The analysis showed that there were spatial clustering and not uniform distribution of incidents occurring along the corridor. The areas deemed to be the most critical accident-prone areas were repeatedly identified as segments S22, S28, S15 and S36. The most crashes, 34, were reported on Segment S22, which had the highest WSI value of 68, representing very high accident conditions. It also revealed that traffic control, non-traffic conditions on the roadway (e.g., over-speeding, mixed traffic operations, roadside commercial activity, inadequate traffic control, poor roadway geometry) are significant factors involved in the accident occurrence. Carrying out the analysis and verifying it in the field, engineering, enforcement, and educational countermeasures were then suggested to increase corridor safety. This study shows that combining several analysis methods gives more reliable and accurate identification of the hot spots and offers a working procedure for road safety management and transportation planning.
Keywords: Accident hotspot, Road safety, Crash severity, Transportation engineering, Black spot analysis, Traffic accident

I. INTRODUCTION

The role of road transportation is very crucial in the development of the economy, connections among regions, social interaction and others. The rise in motorization, urbanization and demand for traffic, however, have played a significant role on the increase of road traffic accidents in the world. It is estimated by the World Health Organization that 1.19 million deaths result from road traffic crashes every year; a large number of these are in developing countries [1]. Most of the road transport accidents in India are because of mixed traffic, poor infrastructure, ineffective traffic control, over speeding and unsafe driving [2]. Such accidents cause significant financial, traffic, property damage and social impacts. Roadway hot spots also known as black spots are those areas on the roadway where a higher number of accidents than expected by frequency or severity occur relative to other roadway areas [3]. Locating those sites is key to the adoption of targeted safety interventions and enhance transportation system performance. There are a number of methods known in identifying hot spots: Accident Frequency Method, Weighted Severity Index, Crash Severity Index, Critical Rate Method, Moving Average Method and Accident Density Method [4].

However, particular approaches have their strengths and weaknesses. Accident severity is not considered by frequency-based approaches, and accident concentration and traffic exposure may not be considered by severity-based approaches [5]. More recent studies recommend approaches combining various methods for a more accurate and complete identification of hotspots [6]. Sirhind Khanna Corridor on a National Highway 44 (NH-44) is an economic corridor that connects the industrial, commercial & residential development areas of Punjab. The corridor sees a high volume of pedestrian, bus and heavy vehicle, motorcycle, tractor, and car traffic. The concentration of commerce activities on the road side, settlements in the village, intersections and commingle traffic conditions are significant factors that cause accidents.

The primary aim of this study is to find a list of accident hotspots along the Sirhind – Khanna section of the corridor with ease by applying multiple analytical techniques and to propose appropriate safety countermeasures considering the observed state of the roadway and the characteristics of the accidents. The study's significance is that, given the absence of public or open datasets and the limitations of advanced GIS and machine learning methodologies in the majority of transportation systems, it offers an intuitive and data-driven tool for identifying accident hotspot areas. The study has significance because it creates an intuitive and data-driven approach to identifying accident hotspot areas for use in those transportation systems where access to public or open datasets is limited, thus rendering the application of advanced methodologies for GIS and machine learning difficult.

II. LITERATURE REVIEW

Several researchers have studied accident hotspot identification using different analytical techniques. Elvik et al. (2008) emphasized that accident frequency methods alone are insufficient because they do not consider accident severity or traffic exposure. Montella et al. (2010) highlighted the importance of statistical and severity-based approaches for improving hotspot identification reliability. Bisht and Tiwari (2023) recommended integrated multi-method approaches combining frequency, severity, and statistical techniques to obtain more accurate hotspot identification results. Jing et al. (2025) reported that accident hotspots are spatially concentrated due to recurring hazardous conditions such as poor road geometry and mixed traffic movement. Several studies have identified major contributing factors to road accidents, including over-speeding, distracted driving, poor road geometry, inadequate signage, and mixed traffic conditions. Kumar et al. (2021) stated that road accidents result from the interaction of human, vehicle, infrastructure, and environmental factors.

Severity-based methods such as the Weighted Severity Index (WSI) and Crash Severity Index (CSI) have been widely applied in road safety studies. Prasad et al. (2022) observed that WSI provides better prioritization of hazardous locations compared to simple accident frequency methods, while Chen et al. (2021) noted that CSI is effective in identifying locations with fewer but severe crashes. Recent studies also emphasize the importance of linking hotspot identification with targeted safety countermeasures. PIARC (2019) reported that engineering improvements, traffic enforcement, and public awareness programs can significantly reduce accident frequency and severity at identified hotspots. Despite extensive research, limited studies have focused on corridor-specific hotspot identification using non-GIS multi-method approaches in Punjab. Therefore, this study applies multiple analytical techniques to identify accident hotspots and propose practical safety countermeasures along the Sirhind–Khanna Road corridor.

III. METHODOLOGY

A. Study Area

The study was carried out on the National Highway 44 (NH-44) in Sirhind–Khanna Road of Punjab, India. The corridor is 20 kms long between Sirhind and Khanna bus stand and is a vital transportation corridor of industrial zones, agricultural markets and residential areas. The mix of traffic flowing through the corridor consists of both passenger vehicles and heavy commercial vehicles, as well as buses, motorcycles and tractors. The corridor has a mix of traffic operations - passenger vehicles, heavy commercial vehicles, buses, motorcycles and tractors, as well as pedestrians. Intersections, access points, roadside commercial activities, bus stops and village settlements are some of the aspects of the roadway that cause complex traffic interactions and the occurrence of accidents. The roadway is, for the most part, straight and has a few horizontal curves and at-grade intersections. During field investigations, the installation of inadequate pedestrian facilities, poor lighting and inadequacies in pavement, pavement markings and uncontrolled roadside access to the motorway were noted.

B. Data Collection

The accident data was collected with the help of records from traffic police section of Punjab and highway authorities for 5 years from 2020 to 2024.The data of accidents during the last 5 years 2020-2024 was retrieved from the Traffic police section of the Punjab concerned and concerned highway authorities. The data collected encompassed:

1) Accident location and types of collision
2) Date and time of occurrence
3) Severity classification
4) Vehicle involvement
5) Weather condition and probable accident causes

Roadway geometry, traffic, pavement, visibility, roadside activity and control measures were evaluated at identified hotspot locations through supplementary field investigations.

To allow detailed spatial analysis 40 segments of 500 m were divided into the study corridor. Supplementary field investigations were carried out at known hotspot areas, to evaluate roadway geometry, traffic characteristics, condition of the pavement, visibility, roadside activities, and traffic control measures. To enable detailed spatial analysis the study corridor was divided into 40 equal segments of 500 m long.

C. Hotspot Identification Methods

Six hotspot identification methods were used for each, to leverage against methodological limitations of individual approaches and to enhance reliability.

1) Accident Frequency Method

The Accident Frequency Method detects hotspots as the number of accidents per segment over a predefined study period. High –risk locations were those having a consistently high number of accidents. The analysis showed that S22 had the highest number of crashes with 34, S28 had 32 crashes, and S15 had 31.

Table 1. Segment Prioritization Using Crash Frequency

Segment Id	Total crash	Annual frequency	Priority level
S22	34	6.8	High
S28	32	6.4	High
S15	31	6.2	High
S36	30	6.0	Medium

This is because the findings suggest that accidents occurred in certain sections of the corridor and not evenly distributed.

2) Weighted Severity Index (WSI)

The Weighted Severity Index is one way to factor accident severity into hotspot analysis by assigning weighted values to each of the various types of accidents [8]. In this study, the following weights were used:

- ✓ Fatal accidents = 3
- ✓ Serious injury accidents = 2
- ✓ Minor injury accidents = 1

The WSI was calculated using:

WSI = (3 × Fatal) + (2 × Serious Injury) + (1 × Minor Injury)

According to the WSI analysis, location S22 is the most dangerous location having the WSI score of 68. Segments S15 and S28 showed WSI values of 61 and S36 showed WSI value of 59. This analysis revealed that certain segments with the relatively low accident rate had a high level of severity, reinforcing the necessity to use a severity analysis when identifying hotspots [9].

Table 2. Segment Prioritization by Weighted Severity Index (WSI)

Segment id	Fatal	Serious	Minor	Total WSI=(fatal×3) +(serious×2) +(minor×1)
S22	10	14	10	WSI= (10×3) +(14×2) +(10×1) =68
S15	9	12	10	61
S28	8	13	11	61
S36	9	11	10	59

3) Crash Severity Index (CSI)

The Crash Severity Index measures the proportion of crashes to severe crashes [10]. This approach is useful for finding sites that could have worse outcomes in the event of a severe accident that might not be detected by a simple frequency analysis. The CSI analysis shows that segments S22, S28, S15 and S36 had not only high accident rates but also high collision severity scores, and were identified as critical hotspots.

Table 3. Hotspot prioritization using CSI

Segment ID	Total WSI	Total crash	Crash severity index = Total WSI/total crashes
S22	68	34	CSI=68/34= 2.00
S15	61	31	1.97
S28	61	32	1.91
S36	59	30	1.97

4) *Critical Rate Method*

The study Critical Rate Method (CRM) is a statistical method to assess the relationship between the accident rates observed and the accident rates expected, based on the amount of traffic exposure [11]. An average daily traffic volume of about 28,000 vehicles/day is currently running in the study corridor. The Critical Rate analysis revealed that the identified hotspot segments were clearly outside the limits of the random variation, thereby proving that the observed accident occurrences are an actual trend, and not just a random variation.

$$\text{Accident Rate } (Ri) = (Ni \times 10^6) / (L \times 365 \times ADT)$$
$$\text{Critical Rate } (Rc) = Ravg + K \times \sqrt{}(Ravg / (ADT \times 356 \times L))$$

Whereas:
Segment length (L) = 0.5 km
·ADT = 28,000 vehicles/day
·K = 1.645
·Total Corridor length= 20km

Table 4. Critical Rate Method Analysis

Segment ID	Total crashes	Ri	Rc	Classification
S22	34	6.65	1.41	Hotspot
S28	32	6.26	1.41	Hotspot
S15	31	6.07	1.41	Hotspot
S36	30	5.87	1.41	Hotspot

5) *Moving Average Method*

Continuous accident-prone segments in the corridor were identified from the corridors using the following method: the Moving Average Method was performed, with the size of the window taking into consideration three segments [12]. The analysis found a persistent zone of hotspots, from 10 km to 15 km, across the corridor suggesting that the occurrence of accidents is dependent on corridor-level conditions of the roadway and operations not specific incident conditions. The window shifts as it rolls from one segment to the next and an average is generated, which hones in on segments that may comprise a larger section of an accident-prone area. This method uses the following formula: Moving Average

$$MAi = (Ni - 1 + Ni + Ni + 1) / 3$$

Where:
MAi = Moving average value for segment i
Ni-1 = Number of accidents in the previous segment
Ni = Number of accidents in the current segment
Ni+1 = Number of accidents in the next segment

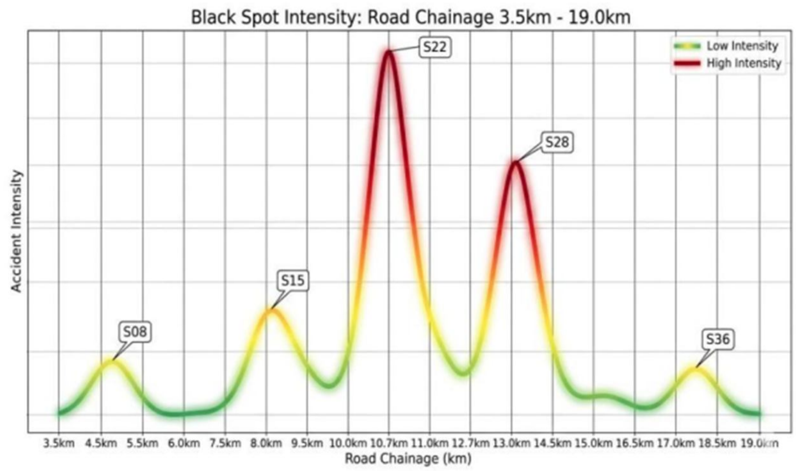

Figure 1. Black Spot Intensive Road Chainage Analysis

6) Accident Density Method

The Accident Density Method is used to determine the concentration of accidents over the length of a roadway in km per accident [13]. Critical segments comprised of 1 km inflows of accidents ranged from 44 to 68 accidents/km, well higher than the corridor average of 24.1 accidents/km. The results validated those accidents are concentrated in certain sections of corridors. Accident density overcomes the limitations of frequency counts insofar as it also takes into account the spatial dimension of accident locations, in that it relates accidents to the length of the roadway involved. This method uses the following formula: Accident Density.

$$ADi = Ni / Li$$

Where:
ADi = Accident density for segment i
Ni = Total number of accidents in segment i
Li = Length of segment i (in km)
Since each segment in this study is 500 meters (i.e., 0.5 km), the formula simplifies to: ADi = Ni / 0.5

IV. RESULT AND DISCUSSION

A. Temporal Distribution of Accidents

A large number of differences were found in accident frequency, year, month, day of the week and time of the day. Higher traffic numbers resulted in higher accident frequencies in peak traffic times because there are more interactions and congestion in such times. Dressed drivers, insufficient lighting conditions, reduced visibility, driver fatigue also caused a significant number of night time accidents [14]. Overtaking at an inappropriate speed and overtaking itself were found to be significant causes of accidents.

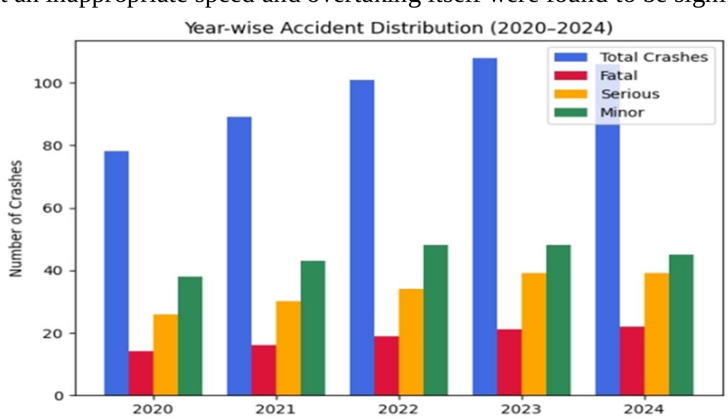

Figure 2. Year-Wise Accident Distribution (2020–2024)

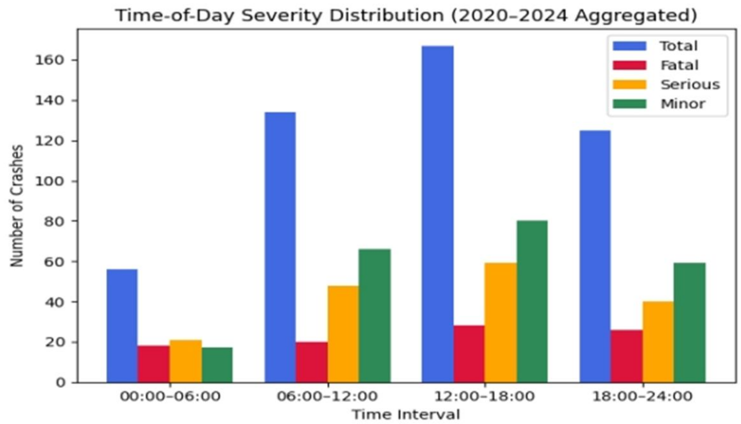

Figure 3. Time-of-Day Distribution of Accidents

B. *Major Contributing Factors*

The study pointed out some factors contributing to the occurrence of accidents along the corridor.

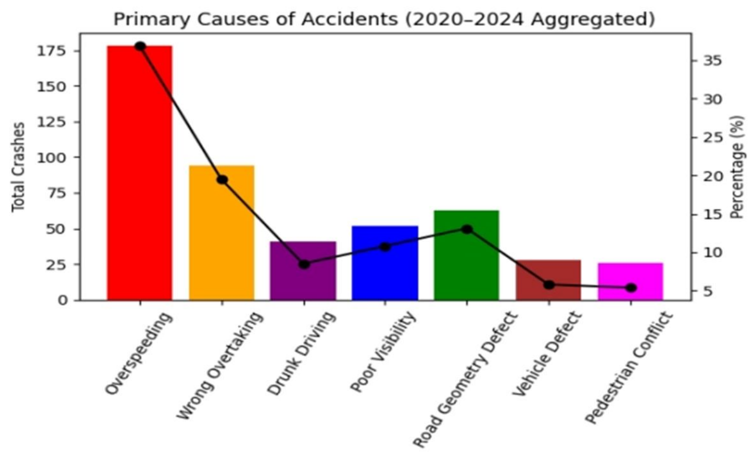

Figure 4. Probable Causes of Traffic Accidents

Various contributing factors that were observed during field investigation included:

- Mixed traffic operations
- Roadside commercial activities
- Inadequate traffic control
- Poor roadway geometry
- Lack of pedestrian facilities
- Poor road markings
- Insufficient lighting
- High roadside interaction

The results are consistent with the previous transportation safety research in developing countries [15].

C. *Identification of Critical Hotspots*

All integrated analysis methods revealed the same segments as the riskiest areas: segments S22, S28, S15 and S36.

1) Segment S22: The most serious hotspot – the one that had the highest frequency of crashes, the highest WSI score, the most critical crash outcomes and the most commercial uses near the sides of the road – was in a segment of S22. Field observations showed poor traffic control and lack of pedestrian facilities, high interaction with the roadside and high number of vehicle conflicts. This segment was seen at Mandi Gobindgarh intersection and the main flyover or Mandi Gobindgarh.

2) Segment S28: There were several incidents on S28 near Daheru Village intersection caused by insufficient traffic control in intersections, mixed traffic flows, and conflicts associated with turning movements.
3) Segment S15: High-risk behaviors such as over speeding, lack of signage and the lack of pedestrian facilities were identified for severe collisions in Segment S15.
4) Segment S36: The main reason for the severe occurrence of accidents in Segment S36 (situated in front of Infront KFC and McDonald) was due to over-speeding, merging conflicts along with high pedestrian activity where there is no pedestrian facility, pavement deficiency and inadequate road marking. Results are consistent across a variety of analytical methods, increasing the confidence in hotspot identification and that these areas are locations of true accident-prone areas.

D. Comparative Evaluation of Analytical Methods

Comparative evaluation, results of which were found to be unsatisfactory, showed that the one particular analytical method would not be enough for a complete hotspot identification. The Accident Frequency Method correctly pinpointed areas where repetitive accidents are occurring but it was unable to consider the severity of the crashes. Severity-based approaches (WSI and CSI) identified areas linked to fatal and severe crashes. The Critical Rate Method proved to be more statistically reliable by including traffic exposure; the Moving Average and Accident Density methods were successful in identifying spatial clustering of accidents. Adopting all six methods enhanced both the accuracy of hotspot identification and the methodological approach involved to thus mitigate methodological bias.

E. Recommended Safety Countermeasures

Several recommendations are provided to resolve the above safety problems based on the analytical results described and confirmed in the field, with respect to its solutions through the 3E philosophy: Engineering, Enforcement, and Education.

1) Engineering Measures

The proposed engineering measures include:
·Improvement of roadway geometry
·Shoulder widening
·Installation of reflective road markings
·Improvement of street lighting
·Provision of pedestrian crossing facilities
·Construction of dedicated turning lanes
·Installation of warning signs and speed calming measures
·Pavement rehabilitation
Engineering controls have been demonstrated to effectively decrease accident frequency and the severity of accidents [16].

2) Enforcement Measures

Recommended enforcement measures include:
·Strict speed monitoring
·Automated speed cameras
·Increased traffic police surveillance
·Enforcement against dangerous overtaking
·Helmet and seat belt enforcement
·Drunk driving checks

3) Educational Measures

Educational strategies include:
·Public road safety awareness campaigns
·Driver education programs
·School-based safety education
·Community participation initiatives
Combination application of engineering, enforcement and education measures is expected to enhance the safety of the transportation system and minimize accident rates within the corridor.

V. CONCLUSIONS

A detailed multi-methods study for identification of an accident hotspot on Sirhind-Khanna Road corridor in Punjab, India was presented. The analysis used five years of accidents data (2020-2024) to be taken through six analytical methods which were Accident Frequency Method, Weighted Severity Index, Crash Severity Index, Critical Rate Method, Moving Average Method, and Accident Density Method. The results showed that the incidence of accidents along the corridor was very clustered and localized. High accident frequencies, high accident severities along with statistically significant accident frequencies and consistently ranked within the list of critical accident areas, segments S22, S28, S15, and S36 were identified as critical accident areas. The safety score for each segment was calculated, with Segment S22 having the top crash frequency and the highest WSI score highlighting major safety issues. The study also showed that using several analytical methods resulted in more reliable and accurate identification of hotspots than a single analytical method. Over speeding, mixed traffic, lack of traffic control, roadside commercial activity, roadway geometry, poor, lack of pedestrian facility were the major contributing factors identified. From the results, several engineering, enforcement, and educational solutions were recommended to increase the safety along the corridor. The study offers practical and reliable tools for transportation safety analysis and accident hotspot prioritization in situations with limited data. Spatial analysis using GIS, intelligent transportation systems, machine learning techniques for advanced accident prediction and pro-active road safety management can be integrated in future research.

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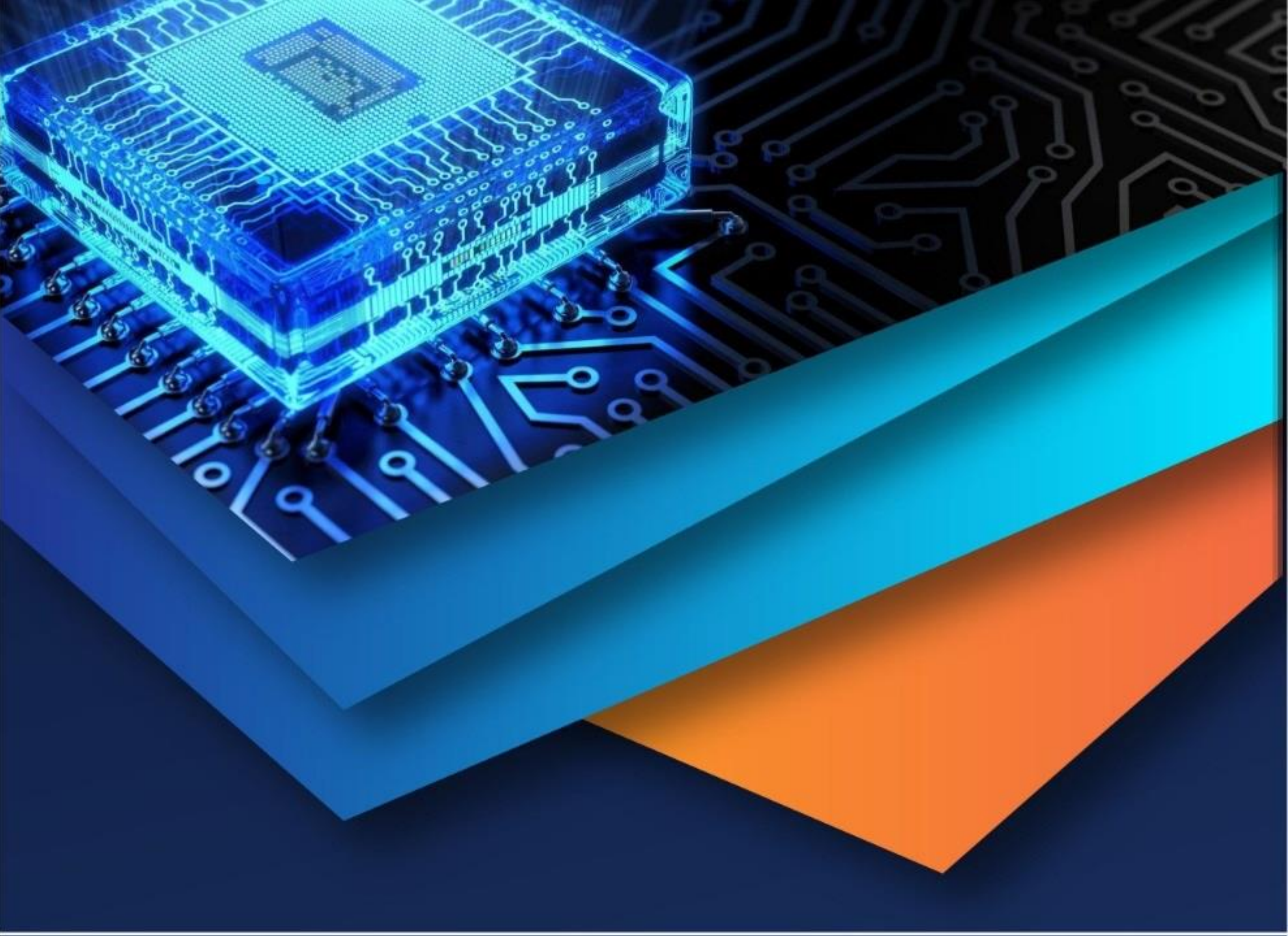

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