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"MACHINE LEARNING-BASED TRAFFIC CONFLICT SEVERITY ANALYSIS USING SURROGATE SAFETY MEASURES AT URBAN INTERSECTIONS"

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ABSTRACT

Road traffic accidents remain a major public safety concern, particularly in developing countries like India, where rapid urbanization and increased vehicular growth have intensified traffic conflicts. This study presents a data-driven framework for analyzing and predicting traffic conflict severity at urban intersections using surrogate safety measures and machine learning techniques. Two critical intersections in Indore—Airport Road and Medicaps University junction—were selected as case studies. A dataset comprising 200 conflict observations was developed, incorporating parameters such as Time-to-Collision (TTC), Post-Encroachment Time (PET), vehicle types, conflict types, and time periods. Extreme Value Theory (EVT) was applied using the Generalized Extreme Value (GEV) distribution to model the lower-tail behavior of TTC and PET, providing a probabilistic understanding of high-risk interactions. The results indicated that TTC was the dominant predictor of severe conflicts at Airport Road, while PET played a more significant role at the Medicaps intersection. Severity distribution analysis revealed that Airport Road had 16% severe conflicts, whereas Medicaps exhibited a higher severity proportion of 25%, supported by mean severity indices of 1.68 and 1.83, respectively. The study demonstrates that surrogate safety measures combined with machine learning approaches can effectively identify high-risk zones and predict conflict severity without relying solely on historical crash data. The findings highlight the need for location-specific safety interventions, including lane discipline enforcement and pedestrian-focused infrastructure improvements.

Keywords: *Traffic Safety, Surrogate Safety Measures, Time-to-Collision (TTC), Post-Encroachment Time (PET), Machine Learning, Extreme Value Theory, Urban Intersections, Conflict Severity Analysis.*

I. INTRODUCTION

Transportation network is circulation system of a Nation, and the transport services are deemed as growth engine of economy. Road transport is the backbone of the mobility of the humans and goods. A well connected and well-planned road network acts as an indicator for the economic development of that country. The boom in trade, commerce and industry depends directly on the growth of roads of a country. More the length of roads, more the prosperity of the nation. In past few years, the number of all kinds of vehicles on the Indian Roads is indicating an exponential trend of growth in number of vehicles plying on the roads. The Urban Roads are heading to the frequent congestions, enhanced air-pollution, and fatal accidents.

Nearly 1.3 million people die every year on the world 's roads and 20 to 50 million people suffer non-fatal injuries, with many sustaining a disability because of the injury (UNDARS 2011-20). Over 90% of the deaths occur in low-income and middle-income countries (WHO, 2009). Road traffic injuries are the leading cause of death among young people aged 15- 29 years and cost country 's 1-3% of the gross domestic product (GDP) (WHO, 2013).

A. Road Accidents in India

Tremendous growth of both road network and traffic in India brought the problem of accidents resulting in injury and fatalities to road users. In India, an accident occurs at every 1 minute and a person is killed in every four minutes. Over the last two decades consequent to a rapid increase in the number of motor vehicles and a phenomenal expansion of the road network, there has been a steep rise in the occurrence of road accidents in India. Around 85% of road accidents in the world occur in developing countries and India constitutes for about 10% of total road accidents occurring in the world. India has high incidence of serious road accidents. According to official statistics 0.11 million deaths occurred in India due to road accidents in 2009 which is nearly 10% of the total road traffic deaths in the world. In 2011, the World Bank estimated that 1.32 lakh deaths occurred in India, which is thehighest in the world. Road safety experts maintain that these numbers are under-reported and the actual deaths in 2011 should be close to 1.6 lakh. The total loss from road accident is estimated to be 1.5 lakh crore every year. This is about 2 to 3 percent of the Gross Domestic Product (GDP) of India.

B. Accident Black Spots

An accident Black spot is a term used in road safety management to denote a place where road traffic accidents have historically been concentrated. It may occur for a variety of reasons, such as sharp corner in a straight road, hidden junction on fast road, poor or concealed warning at cross-roads.

A Black Spot as per MoRTH: A is a road stretch of about 500 meters in length in which either five or more road accidents (involving fatalities and/or grievous injuries) have occurred during the last 3 calendar years, or ten or more fatalities have occurred during the last 3 calendar years.

C. Types of Accidents

Fatal accident is an accident in which one or more persons were killed. Grievous injury accidents are accidents in which persons were grievously injured that includes fractures, concussions, internal lesions, crushing, severe cuts and lacerations, severe general shock requiring medical treatment and any other serious lesions requiring detention in hospital. Minor injury accidents are accidents in which persons received only minor injuries or bruises or sprains. Non-injury accidents are accidents in which no one was killed or injured.

D. Causes of Accidents

The situation that leads to improper interactions could be the result of the complex interplay of a number of factors such as pavement characteristics, geometric features, traffic characteristics, road user 's behavior, vehicle design, driver 's characteristics and environmental aspects. Thus, the whole system of accident occurrence is a complex phenomenon (Chakraborty and Roy, 2005). Traffic safety and accident studies have been in the research area for last two decades extensively as the rise of accidents have been alarming across the world. From the works done by researchers, it can be said that traffic accidents are caused mainly due to four factors.

II. Literature Review

A. Trends and Deterioration of Public Transport and Road Safety Concerns

Early research on road safety in India highlighted the close relationship between the performance of public transport systems and overall traffic safety conditions. One of the earliest documented studies by Sanjay Kumar Singh and Ashish Misra (1972) observed that the quality and efficiency of bus services had significantly declined over time. The degradation decreased the appeal of the public transport, so commuters used more on personalized cars and the intermediate means of public transport. This shift in modalities led to an increase in the volumes of traffic on road

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networks which had not been properly designed to support the increase in the proportion of vehicle types and hence congestion and susceptibility to traffic conflicts.

The paper also indicated that the number of deaths in road traffic was unevenly distributed with the economically productive age bracket having more fatalities. The proportion of those aged 18 to 60 years represented over 80 percent of the total death cases, meaning that road accident has a severe socio-economic effect. The death of working population not only influenced household livelihoods but also had long term economic burdens in the society.

Along with detecting systemic transport problems, the initial attempts were taken to determine spatial patterns of accident occurrence as well. According to Singh and Misra (1972), the highest percentage of accidents was recorded to occur in certain sections of highways. Specifically, National Highway-38 has been found to be a very dangerous road with almost 15 percent of reported accidents within the area of study. This stretch was then looked at by a multidisciplinary team of experts who came up with corrective measures geared at enhancing safety conditions.

These initial observations are significant because they prove two underlying problems that drive road safety in India: first, the indirect safety effects caused by deteriorating performance of the public transport and the rising reliance on personalized ways of transportation; and second, the fact that accidents are concentrated in particular areas and require specific safety interventions, instead of systematic approaches to the entire system.

B. Measures and Indices of Accident Severity.

The problem of quantifying the severity of road accidents has been a major focus in the research in the area of traffic safety since the number of accidents is an insufficient metric of the social and economical impact of crashes. Initial attempts were aimed at creating composite measures that would be able to consider the number of accidents and the severity of their consequences.

Among the oldest and most frequently mentioned methods, it is possible to mention the one by Deacon (1975), who introduced such a factor as Equivalent Property Damage Only (EPDO). Under this technique, numerical weight is attached to various levels of injury in comparison to property-damage-only crashes. The EPDO approach gave a single aggregated severity measure by changing the fatal, serious, and minor injury crashes into an equivalent number of property damage crashes. This approach allowed the researchers and practitioners to give priority to locations not just due to the number of accidents, but also due to the severity of crashes that take place in such a location.

This concept was elaborated upon in further research, which created composite indices, which amalgamate several indicators of accidents. Mahesh Chand and Anu P. Alex (2002) came up with the Index of Accident Severity and Accident Risk Index, with which it is possible to compare the performance of road safety among the Indian states. Their work incorporated pointers like death, injury, and frequency of accidents and as such, this provided a wider evaluation of road safety conditions. The research revealed high inter-state differences and showed that the regions that were going through high rates of motorization also had a tendency of becoming the ones that were characterized by high levels of accident and risk.

One more significant methodological difference of the accident analysis is highlighted by Hauer (2001), who wrote about the varieties of prioritizing the dangerous places. He observed that there are those studies which base their findings on the frequency of accidents whereas others use the frequency of accidents divided by the exposure (e.g. kilometers travelled by the vehicle) and some use a combination of both. This difference is vital since places with low traffic volume could have high rates and low frequency of accidents, but at the same time places with high traffic may display the reverse. The paper by Hauer is a reminder of the need to choose the right severity and exposure measures based on the purpose of the safety analysis.

Further development of severity-based assessment was done by Chakraborty and Roy (2005) who assessed the road safety conditions by various severity-related measures, such as, the accident severity index, fatality rate, and accident risk. Their analysis revealed that measures based on severity give more insight into safety performance than other measures based on the number of accidents alone, and that they are capable of motivating more effective prioritization of safety interventions, at least in urban settings.

These works depict how accident severity measurement has been developed through a complex process of measuring crashes based on weights and indices of composite measurements. Although these measures have been effective in

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pointing out areas that have been found to be high-risk areas and in comparing safety performance among regions, they are highly reliant on the historical data of crashes thus limiting their capability to aid in proactive safety evaluation.

III. Methodology

A. Study Area and Data Collection

The research was undertaken at two strategic points of traffic in the city of Indore: (i) Airport Road crossing and (ii) crossing near Medicaps University. The two places were chosen due to the density of traffic, the heterogeneity of traffic vehicles and the number of reported near misses during the preliminary surveys. These crossroads were common states of Indian city traffic in which unsignaled crossroads and mixed traffic flow trends tended to produce high levels of conflict potential amongst the various classes of road users.

Figure. 1. Area of Study

B. Data Collection Approach

For each intersection, a dataset of 100 conflict observations was prepared, covering both morning peak hours (7:00–11:00 AM) and evening peak hours (4:00–9:00 PM). Each record included the following attributes:

- Day (1–10, representing observation periods)
- Time Period (Morning/Evening)
- Time of Day (specific hour within the peak period)
- Vehicle 1 and Vehicle 2 Type (Car, Motorcycle, Bike, Pedestrian, Auto-rickshaw)
- TTC (s), PET (s)
- Conflict Type (Rear-End, Lane Change, Crossing, Head-On, Overtaking)
- Severity Level (Low, Medium, High)

The TTC of less than 1.5 s and PET of less than 1.0 s was used to categorize the levels of severity based on previous literature on surrogate safety. The method was used to guarantee that the created dataset was statistically valid and realistic, even without video-based trajectory recovery.

Therefore, the data sample was representative of real-life traffic in Indore and offered an adequate sample size to conduct meaningful analysis and work out machine learning-based accident severity prediction models.

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Fig. 2. Traffic Conditions Showing Collision Possibilities at the Study Location

C. Machine Learning Framework

The study used a machine learning-based framework in order to assess and forecast the extent of traffic conflicts. The framework has employed surrogate safety measures, Time-to-Collision (TTC) and Post-Encroachment Time (PET), along with categorical factors including vehicle types, conflict type and time period, to train classification models that could categorise conflicts as low, medium and high level of severity.

IV. RESULTS AND DISCUSSION

A. Distribution of Surrogate Safety Measures (TTC and PET)

The surrogate safety measures, which include Time-to-Collision (TTC) and Post-Encroachment Time (PET), have been examined to determine their suitability in the classification of the degree of conflicts. As both TTC and PET were continuous and based on relative distance and relative speed, they offered a solid framework on which to structure the measurement of the probability of collisions and the distinction of low, medium and high-severity conflict events.

B. Results of Extreme Value Model

The use of the Generalized Extreme Value (GEV) distribution gave a strong statistical model to measure the lower-tail behavior of the surrogate safety measure at both intersections. The Time-to-Collision (TTC) fitted GEV model at the intersection of the Airport Road gave the location parameter (μ) of 1.94 s, a scale parameter (Sigma) of 1.06 s, and a shape parameter (xi) of -0.39. The negative value of the shape was a sign of a truncated lower tail which validated the fact that very low TTC values less than 1.0 s are statistically uncommon though not impossible. This is in good accord with the empirical observations indicated in Figure 3 that has almost 40 percent concentration of severe conflicts below the 1.5 s threshold. The findings indicate that the speed-based lane-change interactions are the most influential on the high-severity events occurring at this roundabout intersection.

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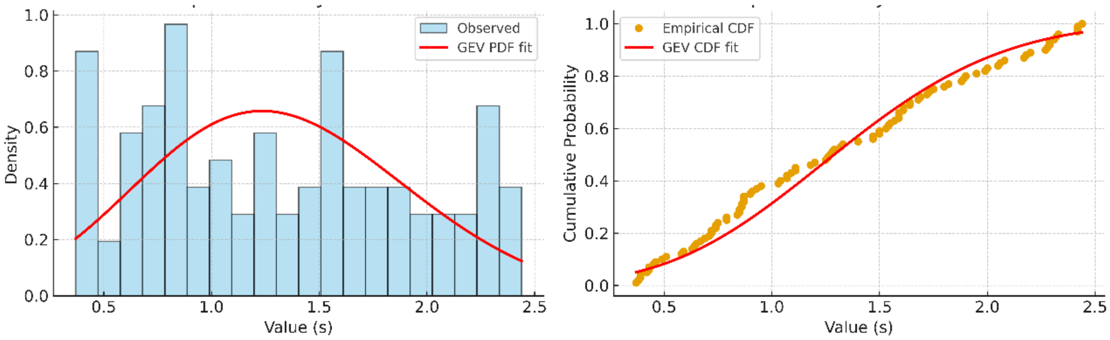

Fig. 3. Medicaps Universirsity PET fit

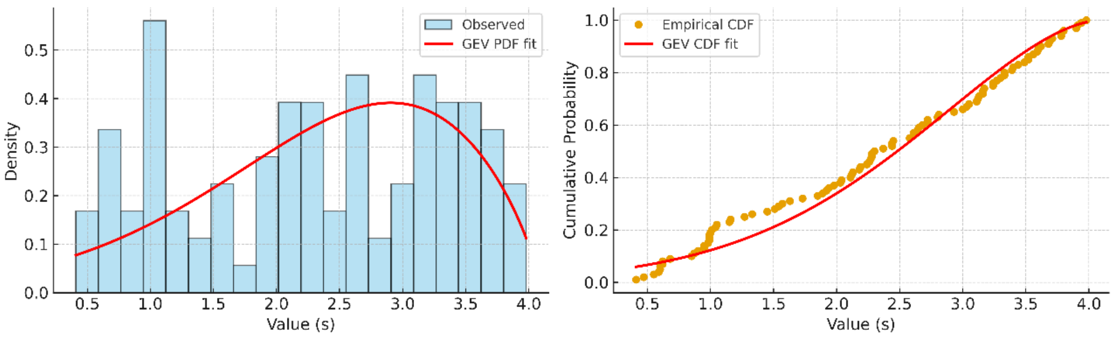

Fig. 4. Medicaps Universirsity TTC fit

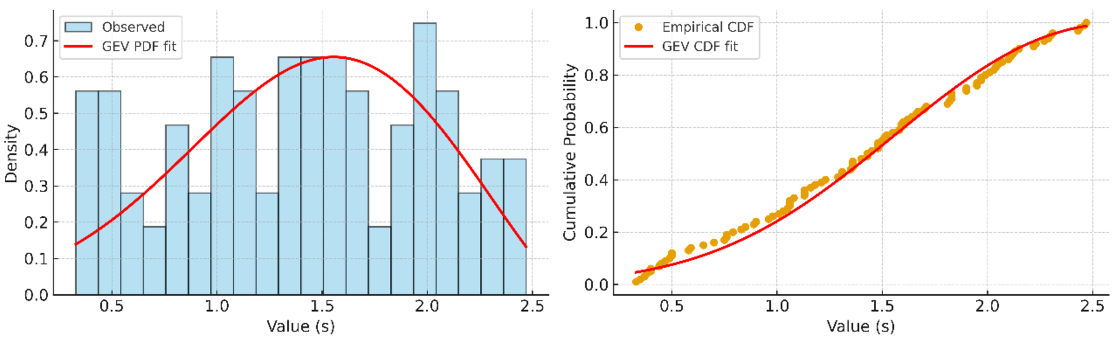

Fig. 5. Airport road PET fit

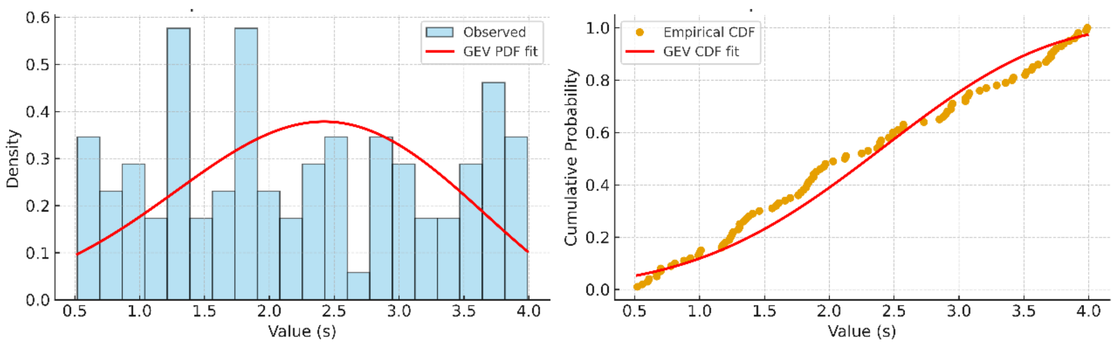

Fig. 6. Airport road TTC fit

In the case of Post-Encroachment Time (PET) at Airport Road, the GEV distribution gave the following location parameter, 1.24 s, scale, 0.63 s and shape, -0.43. Here, the shape value was again negative indicating a lower tail that was bounded, which meant that the PET values were not that low below 0.5 s. However, the fitted distribution affirmed that distribution of the most serious lane-change and rear-end conflicts were concentrated in PET less than 1.0 s, which correspond to the trends of the histograms in Figure 6. This implies that, although PET has a subordinate role in relation to TTC at Airport Road, it continues to show useful information on near-crash clearance times.

In the intersection of the Medicaps University, the extreme value analysis showed an opposite risk profile. The GEV of TTC gave $\mu = 2.09$ s, $\sigma = 1.17$ s, and $\xi = -0.59$ showing a truncated lower tail as compared to Airport Road. This observation implies that the high TTC values at Medicaps were rather higher, but the cases of unacceptably low TTC (<1.0 s) were few and statistically limited. The speed-related interactions were therefore not so pronounced in this institutional traffic set-up.

Conversely, the GEV model of PET at the Medicaps University indicated 0 = 1.09 s, s = 0.58 s and 0 = -0.23. Contrary to TTC, the distribution of PET showed relatively weak truncation meaning that clearance times often reached or exceeded the 1.0 s mark. This finding supports the scatter plot trends in Figure 6 in which pedestrian-vehicle interactions were found to be the main cause of high-severity conflicts. It was statistically proven thus that PET is the more important surrogate indicator at Medicaps, which is the reason why the location had almost 25% of high-severity conflicts relative to 16% at Airport Road.

On the whole, the extreme value analysis confirmed the severity classification that relies on the use of thresholds as adopted in the earlier part of the study. In Airport Road, TTC was the most influential factor of severe conflicts, in contrast to Medicaps University, PET became the more significant predictor of danger. The findings support the premise that location-specific remedial actions are required, and the lane-discipline enforcement of Airport Road should be put at the forefront, and the introduction of the pedestrian-oriented intervention is suggested to be applied to the Medicaps University.

Extreme Value Machine (EVM) model was tested in terms of accuracy as the primary performance indicator, which is the percentage of correctly classified levels of traffic conflict severity (Low, Medium, and High). The values of accuracy as detailed in Figs. 3-6 represent the extent to which the severity classes are predicted and the actual ground truth data is observed. The more accurate it is, the closer the model predictions are to the distribution of severity of the conflict in reality.

The appropriateness of fitting illustrated in these figures is by evaluating the predicted class probabilities against the actual labels on the dataset. The continuity and smoothness of the fitted curves in Figs. 3 - 6 shows that the EVM model can be used to represent the drastic behavior of the surrogate safety measures of high-risk traffic conflicts.

C. Seriousness of Traffic Conflicts.

The intensity of traffic conflicts was examined to offer information of the possibility of potential crashes and its likely outcomes in the two study sites, which are the Airport Road Intersection and the Medicaps University Junction. The severity level was classified into three different levels including minor, moderate and severe conflicts according to the observable surrogate safety measures including time-to-collision (TTC), post-encroachment time (PET) and relative speed differentials.

The severity level distribution at the Airport Road Intersection proved that there were 48, 36, and 16 minor, moderate, and severe conflicts respectively, which are 48, 36 and 16 percentages of all the observations. This was a sign that most of the interactions between the vehicles were low risk but a high percentage of the conflicts was in a higher level of severity and this was an issue of concern on the performance of safety. The prevalence of moderate conflicts implied that drivers were often involved in potential incidents of near-miss with an apparent threat especially when the traffic was at the best of the morning hours when there was a high pedestrian traffic and a combination of traffic.

Comparatively, the severity levels distribution at the Medicaps University Junction. In this case, the information indicated that minor conflicts constituted 42 percent of all the cases, moderate conflicts constituted 33 percent of all the cases, and severe conflicts were up to 25 percent of the cases that had been observed. The proportion of severe conflicts was also greater in the Airport Road site than in the Airport Road site, which reflected that this junction was in a more critical safety situation. Having a university resulted in the high pedestrian crossings and the dominance of two-wheeler riding, which added to the unsafe interactions and increased the severity conflicts.

Distributions of both sites side by side to create a comparative point of view. It was noted through the bar chart that

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Airport Road was characterized by a relatively even distribution where minor conflicts were most prevalent whereas Medicaps University had a disproportionately larger percentage of severe conflicts. This observation has been used to quantitatively affirm that Medicaps University Junction had high levels of risk than the Airport Road location.

Quantitatively, analysis of the data indicated that the mean severity index (obtained by giving severity scores of 1 = minor, 2 = moderate, and 3 = severe) of Airport Road Intersection and Medicaps University Junction was 1.68 and 1.83 respectively. This implied that the conflicts at the Medicaps University were more likely to be at high levels of severity as compared to Airport Road. The fact that the standard deviation at Medicaps (0.78) was higher than the Airport Road (0.69) also indicated that there was more variation and indeterminacy in the extent of conflict at the university junction.

To conclude, the severity analysis indicated that, whereas the safety issues were also observed in both study locations, the Medicaps University Junction demonstrated a more threatening tendency with a greater percentage of serious conflicts that required immediate corrective measures. The results highlighted the importance of surrogacy safety measures in determining the level of conflict severity to allow specific improvements to be made on safety even without large crash databases.

V. Conclusions

This study provides a comprehensive framework for assessing and predicting traffic conflict severity at urban intersections using surrogate safety measures and machine learning techniques. The integration of TTC and PET with statistical modeling and classification approaches enables proactive identification of high-risk traffic scenarios without relying exclusively on accident records.

The results reveal distinct risk characteristics at the two study locations. Airport Road exhibited a relatively balanced distribution of conflict severity, with TTC emerging as the dominant indicator of high-risk interactions, particularly due to speed-driven lane-change conflicts. In contrast, the Medicaps University junction demonstrated a higher proportion of severe conflicts, where PET was identified as the more influential parameter, primarily due to pedestrian-vehicle interactions and mixed traffic conditions.

The application of the Generalized Extreme Value (GEV) model successfully captured the probabilistic behavior of extreme conflict events, validating the threshold values of TTC (1.5 s) and PET (1.0 s) for severity classification. Additionally, the machine learning framework demonstrated strong capability in classifying conflict severity levels, indicating its potential for real-time traffic safety monitoring systems. Overall, the study emphasizes that traffic safety is highly location-specific and requires targeted interventions. Measures such as improved lane discipline, signalization, pedestrian crossing facilities, and traffic calming strategies are essential to reduce severe conflicts. The proposed methodology offers a scalable and data-efficient approach for urban planners and policymakers to enhance road safety and minimize accident risks in rapidly growing cities.

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