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Pedestrian Safety Evaluation at Signalized Intersections Using (SSM)

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Abstract

Urban traffic management and transportation engineering best identify areas related to pedestrian safety at signalised intersections. Despite the increase in infrastructure and signal control systems, pedestrians continue to be vulnerable road users, who are at risk at disproportionate rates compared to motorists. However, current traditional crash-based safety evaluation techniques are poor in predicting risk because of the relatively low frequency of collisions that occur between pedestrians and vehicles, thus creating unreliable estimates of the risk and delaying the implementation of preventive strategies. Therefore, in this study, the evaluation of pedestrian safety is achieved using Surrogate Safety Measures (SSM), namely, Time to collision (TTC), Post encroachment time (PET) and vehicle pedestrian conflict rates. The SSMS contribute proactively in identifying near misses and high-risk situations before accidents happen. A high volume network of signalised intersections was studied in the mid-sized urban environment, and data were collected. Detailed movement paths of both vehicles and pedestrians were extracted using advanced video-based trajectory analysis tools. Trajectories from these methods were calculated, and SSMs were calculated and analysed for different intersection designs and operational conditions. The results showed a strong positive correlation between the conflict rates that are elevated, lower TTC and PET values and historical crash records, indicating the effectiveness of SSMs as useful measures of pedestrian risk. In addition, certain geometric configurations were shown to be important factors in terms of increased conflict rates, including broader crossings as well as insufficient pedestrian clearance intervals. The study proposes targeted engineering treatments and signal timing modifications based on these findings. The research shows the need to incorporate SSMs in the current practices of traffic safety management and lead it in a proactive approach toward mitigation of risk.

Keywords:
Surrogate Safety Measures (SSM), Time to collision (TTC), Post encroachment time (PET), Pedestrian Safety, Signalised Intersections

1. Introduction

1.1. Background

Safety for pedestrians still remains a persistent and growing problem within urban settings where the paths of vehicles and pedestrians often cross. The complexity of interaction between motorized traffic and vulnerable road users as city continues to urbanize and population grow. Despite great efforts to enhance transportation infrastructure, globally pedestrians continue to account for disproportionately high percentage of fatalities and serious injuries in traffic injuries

(Nogayeva et al., 2020). The World Health Organization estimates that about one in four road traffic deaths is due to pedestrians, which calls for more effective intervention measures in urban areas. Signalized intersections are particularly planned to control the movement of vehicles and pedestrians through noted stages. Theoretically, these intersections would improve the safety by creating an interval for crossing that is predictable and less likely to result in collisions (Wang et al. 2021). Paradoxically, while signalized intersections often serve as the high priority targets for pedestrian injuries and fatalities. This phenomenon is largely due to several factors. The dynamic environment as a result of signalized intersections (with turning vehicles, lane changes and pedestrian crossings) makes it complex with many conflict points that make it first. Second, factors of human behaviour based on signal timing, driver impatience, pedestrian non compliance and other human factors can result in unsafe interactions even within a controlled environment (Sheykhfard et al., 2021).

In addition, however, traffic engineer and operational aspects of signalized intersections can introduce compromises to pedestrian safety without notice. Some of the common issues that can be seen at most intersections are insufficient crossing time for pedestrians, poor visible due to large curb radii and lack of refuge islands, and inadequate signage. High vehicular volumes and speed firstly also contribute towards increasing risk, whereby drivers may put making light cycles over giving to pedestrians. Furthermore, right turn on red or other left turns across pedestrian paths also greatly increase vehicle − pedestrian conflict risk (Chen & Fan, 2018). In turn, the primary methods of assessing pedestrian safety have been based on crash data analysis. However, these approaches are limited in that they cannot resolve for crashes in urban areas where pedestrian crashes are less frequent but more serious. Pedestrian-involved collisions have a low frequency and small sample sizes lasting them statistically to come to sound conclusions regarding the causative risk factors. In addition, crash data only takes into account the severe, injury or death resulting crashes and neglects the countless near miss events that are critical indications of the systemic safety issues (Arteaga et al., 2020).

Facing these difficulties, researchers and practitioners have promoted the utility of using proactive safety analysis methods including SSMs (Hong et al., 2025). They find these measures to provide insight into potential safety problems from conflicts, near misses, critical interactions in air traffic, before they become crashes. SSMs concentrate on the dynamic exchange of road clients; therefore argue a more touchy and quickly point by point assessment of hazard at the light signalized intersection. In short, the function of signalized intersections in organizing urban traffic flow is important, but they present associated risks for pedestrians that must be carefully assessed and acted upon (Rodegerdts et al., 2004). Targeted interventions to mitigate pedestrian vulnerability at these locations require a deeper understanding of the factors at work. SSM can be employed to innovate and be practical in supplementing to traditional analyses of crash based approaches to more fully consider pedestrian safety and to develop safer streets more inclusive of pedestrians (Mussah & Adu-Gyamfi, 2022).

1.2. Problem Statement

Typically, pedestrian safety evaluations at intersections have relied on the historical crash data. Although crash based assessments give us important insights into high risk locations and occurrence of previous crashes, they form major limitations when used as a principal method of proactive safety assessment. Both car vs. car and car vs. pedestrian crashes represent rare occurrences in reality, however when these rare events must occur pedestrian victims are much less protected. Pedestrian crashes are relatively severe, though they occur comparatively infrequently at any given location, so their records do not provide statistically meaningful information for drawing conclusions about patterns or other meaningful conclusions without the use of other knowledge. Owing to this, there is an underestimation of the actual risks pedestrians are exposed to on a daily basis (Obinguar & Asano, 2021).

Additionally, crash data are inherently reactive in nature, specifically because they are meant to describe what has already happened. Historical crashes alone do not permit timely intervention until many accidents occur and unsafe conditions allow for undetected hazards. Such an approach is not enough to handle the present traffic management strategies, which are aimed towards proactive mitigation of risk arresting accidents before they take place (Abdel-Aty & Yusuf, 2001; Yu & Abdel-Aty, 2013). With these limits increasing the focus of alternative methods that can assess safety without having to wait for crashes to occur. As such, SSMs are a promising solution. Near-miss and traffic conflict observations and analysis are the focus of SSMs, events that are far more likely to occur than crashes. E.g. Time-to-Collision (TTC), Post Visit to Collision (TTC), conflict severity classifications are immediate, direct indicators of possible safety through the actions and interaction of pedestrians and vehicles (Hanandeh et al. 2022). SSMs not only offer a more sensitive and continuous evaluation of intersection safety, but provide detailed information of interaction dynamics. This aids transportation engineers and policy makers and enhances their ability to quickly detect emerging problems, assess the effectiveness of intervention, and determine where to allocate limited resources. Given that urban areas are growing, and pedestrian mobility is increasingly becoming an integral part of sustainable transportation systems, it is no longer merely beneficial, but necessary, to develop surrogate safety analysis as an integral part of pedestrian safety evaluation (Lin et al., 2024).

This study introduces a new method for judging pedestrian safety at signalized intersections by using SSMs and real behavior of people. Different from earlier studies that base their findings on mere simulations and crashes, this one looks at how actual people walk and make sudden decisions that are usually overlooked in usual crash analyses. The study tries to achieve a more accurate and practical risk assessment by combining hard numbers with understandings of how people walk. By combining different methods, the predictive value of SSMs increases and leaves space for better measures to protect cities.

1.3. Research Objectives

This study aims to:

- Evaluate pedestrian safety at signalized intersections using SSM.
- Compare surrogate safety outcomes with crash history.
- Identify intersection characteristics associated with higher pedestrian risks.
- Recommend improvements based on findings.

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2. Literature Review

2.1. Pedestrian Safety at Intersections

Pedestrian intersections have always been viewed as points of vulnerability for pedestrians in urban transportation networks. In fact, a multitude of studies consistently claim that intersections, particularly signalized ones, are hotspots for pedestrian vehicle conflicts. Several interrelated factors account for the glaringly high pedestrian risk at these places. It is also highly associated with volume as the greater the level of vehicles in the traffic, the greater the chances that pedestrians would interact with vehicles, and thereby the greater the probability of conflict between pedestrians and drivers (Mukherjee & Mitra, 2020). Vehicle speed has an equally important influence: vehicles moving at greater speeds take longer to stop; this diminishes the time over which drivers and pedestrians can react to a crash; and enhances the danger of vehicle crashes. Results from studies have found that even miniscule increases in average vehicle speeds are associated with an outsized increase in the proportion of pedestrian injuries that are classified as severe (Jurewicz et al., 2016).

Periods of pedestrian crossing signals, their duration and synchronization with vehicular flows are very important reliability factors. Pedestrians are often forced to hurry across the intersection, exposing pedestrians to excessive amount of time within the intersection resulting in the possibility of mid phase crossings of pedestrians against traffic signals. However, with short pedestrian phases or the lack of any pedestrian prioritized signal intervals, such as Leading Pedestrian Intervals (LPIs), this matter is exacerbated (Alhajyaseen & Asano, 2015). Pedestrian safety is also affected by the geometric design of intersections, specifically, crossing distance. Longer exposure times are provided for pedestrians within vehicle pathways due to the wider crossings. Correspondingly, drivers cannot see pedestrians early enough to react before collision because of poor visibility (obstructions, lack of light, or complicated interchange geometry). In general, intersection safety is a multivariate challenge that requires comprehensive, evidence based strategies (Alhajyaseen & Asano, 2015).

2.2. Limitations of Crash-Based Analyses

For transportation risk evaluation, traditional crash based safety evaluations have provided a solid foundation; however, they have significant limitations, most notably when trying to evaluate pedestrian safety. The "small numbers problem" is one of the main problems. Vehicular crashes involving pedestrians occur relatively infrequently compared to vehicular collisions, and most of these crashes take place at signalized intersections. Such infrequency leads to the generation of datasets that are too sparse for the support of statistically robust conclusions, and hence an over reliance on crash records alone to derive risk assessments is compromised. In addition, the crash based methods are inherently reactive rather than proactive. Delay is due to the fact that safety deficiencies are identified only when injuries or fatalities occur, and no interventions are applied until then (Chakraborty et al., 2023). Consequently, potential risks are not addressed until after the harm has happened, which is both ethically and operationally inappropriate. In addition, crash data includes reporting biases (i.e., not all incidents are reported, especially pedestrian conflicts that are not severe). Comparative analyses are additionally complicated by variations in reporting practice among jurisdictions across space and in time. Despite these limitations, crash based studies have not been useful due to the temporal lag in data availability, inconsistencies in crash severity classifications, and lack of contextual information on near miss events. Of all, these limitations point to the necessity for other ways to evaluate a system, i.e. (SSM) that will detect safety concerns earlier and more broadly by focusing on near misses and conflict events rather than waiting on actual crashes (Tarko, 2018).

2.3. (SSM) (SSMs)

However, there exist circumstances in which Crash data is sparse or insufficient; thus, SSMs emerged as very important tools for tractive traffic safety analysis. Currently, traditional crash based safety evaluations require years of data collection, are reactive, requiring progress only after accidents have occurred. Here, on the other hand, SSMs, including Time to Collision (TTC) and Post Encroachment Time (PET) as well as their respective measures of severity score predict near miss events, i.e. those interactions where collision was averted (Sengupta et al, 2024). The Time to Collision (TTC) is the time elapsed before the onset of collision if two road users continue at their respective speeds without altering their respective trajectories (Zheng & Sayed, 2019). Post Encroachment Time (PET) is the time between the first and second users in crossing the same spatial point, and it is used to quantify the severity of possible conflict even in the absence of immediate threat. Ekeanyanwu et al. (2022) mentions conflict severity scores is holistic risk assessment scores that combine variables such as speed, distance, and maneuvering. SSMs rely on trajectory data from video analytics and sensor technologies to identify more hazardous patterns than the crash based ones. Additionally, SSMs allow for assessing intersections, crosswalks and traffic designs under varying conditions to inform urban planners and engineers of actionable insights to their preventive interventions.

2.4. Application of Video Analytics in Safety Evaluation

The advancements in video analytics and machine learning technologies have greatly helped us monitor and evaluate the traffic safety specifically at complicated intersections. Among these technologies, we now have high resolution video detection systems coupled to sophisticated object recognition and tracking algorithms that allow for real time relative pedestrian and vehicle trajectories to be extracted. This capability is essential for carrying out detailed surrogate safety analysis because it can be used to watch near miss events and interaction patterns, without relying only on historical crash data (Lin et al., 2024). The critical events such as pedestrian vehicle conflict, sudden stop, and evasive move can be identified with high precision using computer vision frameworks, deep learning models and automated conflict detection algorithms. In addition, video analytics allows the constant monitoring of intersections under varied traffic conditions including various times of day or weather conditions. The dynamic data collection approach described here provides a more proactive approach for determining safety risks which, in turn, can better inform design, regulation and signal control intervention (Manikonda et al., 2011).

3. Methodology

3.1. Study Area

The study was carried out at five signalized intersections which are significant in the downtown core of Noida, a medium-sized urban centre with high pedestrian activity and dense vehicular traffic. All of these were selected for these intersections based on several combined criteria including very high pedestrian volumes, variety of traffic pattern including private vehicles, public transit, and bicycles, and a history of reported pedestrian incidents. The choice of sites reflects a range of typical urban intersection designs, varying by the number of lanes, signal phasing strategies, as well as pedestrian crossing amenities, such as countdown timers and curb extensions. By that, the study focused on these intersections so that it captured a full range of pedestrian vehicle interaction scenarios due to the real world conditions. Diversity of intersection types helped generalize findings across different intersection typology. Complementing video based behavioral observations, detailed geometric data, traffic control features and historical crash records were obtained for each location to provide a robust dataset for surrogate safety measure analysis.

3.2. Data Collection

Thus, in order to examine pedestrian safety at the signalized intersections, high definition video cameras were stationed in strategic locations at each study site to capture continuous 12 hours of footage, including peak and non-peak traffic times. Video footages captured walked and contacted pedestrian and vehicle trajectories, which can be tracked accurately at the intersection. To account for variability in pedestrian behavior that could occur at different times on a day and in different forms of weather, data collection took multiple days. Recordings were made only under typical dry and clear conditions to minimize the possibility of having to deal with adverse weather that could throw the analysis off its track. It also records environmental conditions like temperature, humidity, wind speed, etc., to determine whether they could have an impact on the behavior of pedestrians and vehicles. To understand the relationship between traffic flow and pedestrian safety risk at each site, each intersection's average daily pedestrian and vehicle volume were calculated and presented in the table below.

Intersection	**Average Daily Pedestrian Volume**	**Average Daily Vehicle Volume**
DM chowk Noida **(A)**	5,000	22,000
Sector 21 Junction (At Modi Mall) **(B)**	4,200	18,500
Sector 58 Junction **(C)**	6,300	24,500
Sector 62 Junction **(D)**	3,800	19,800
Sector-12 Junction (at Noida Stadium) **(E)**	5,500	20,200

3.3. Video Processing and Trajectory Extraction

An advanced machine vision algorithms were used to track and extract trajectories of both pedestrians and vehicles from video data from each intersection, which were then processed using OpenCV, YOLOv5, Python based machine learning models. Background subtraction and Optical flow analysis was used as an object detection techniques in the software along with others to identify the moving entities from the frames of the video. They calibrated the algorithms for detecting such examples as pedestrians and vehicles based on their distinct visual signatures including shape, size, and movement patterns. Therefore, the video feed was processed at 10 fps to allow the tracking to be accurate. The unique identifier was assigned to each moving object across frames, and hence, it was possible to continuously track the position of each object during the recording period. Next, the extracted trajectories were converted to coordinates over time in order to compute their proxies of perceived safety, which included Time-to–Collision (TTC) and

Post-Encroachment Time (PET). It also ensured a high quality data for subsequent analysis of pedestrian-vehicle interactions at signalized intersections.

3.4. Surrogate Safety Measure Computation

The (SSM) (SSMs) that were computed to assess pedestrian safety of signalized intersections in this study were several. In order to compute the TTC, we determined the remaining time potential collision existed if both pedestrians and vehicles kept their current speed. An evaluation of the immediacy threat, (i. e. lower TTC values correspond to higher risk of collision,) is an important metric for evaluation. It was computed as the time interval between when one road user (vehicle or pedestrian) clears a potential conflict zone and another enters the same space, that is, between the Post-Encroachment Time (PET). Dangerous interactions are indicated by a shorter PET. Furthermore, the Conflict Rate was determined based on analysis of video data recording near miss events, instances where a collision nearly happened but was prevented at the very last moment. Rate was expressed per 1000 pedestrian crossings to quantify pedestrian exposure to risk at each intersection. Real-time video processing algorithms were built to track pedestrian and vehicle trajecotry and these SSMs were computed using these algorithms.

3.5. Conflict Severity Classification

Evaluation of pedestrian safety at signalized intersections is often considered in terms of classifying the severity of conflict. Conflict events involving pedestrians and vehicles have been classified meanwhile in the frame of two important (SSM), Time to Collision (TTC), and Post Encroachment Time (PET). TTC, measures the time up to a potential collision if both parties continue on their current paths, while PET indicates how late the pedestrian is from exiting a potential conflict zone and the vehicle is soon entering. To classify conflicts, three severity levels were defined based on specific thresholds for TTC and PET values:

- High Severity: Conflicts with TTC < 1.5 seconds and PET < 1.0 seconds were categorized as high severity. This indicates an imminent collision or near miss with insufficient time for either road user to avoid the conflict.
- Moderate Severity: Conflicts with TTC between 1.5 and 3.0 seconds, and PET between 1.0 and 2.0 seconds, indicated moderate risk. This suggests a significant chance of collision but with a slight buffer for avoidance.
- Low Severity: Conflicts with TTC > 3.0 seconds and PET > 2.0 seconds were considered low severity, indicating a minimal risk with ample time for either party to react.

4. Results

4.1. Descriptive Statistics of SSMs

The analysis of SSMs revealed varying levels of pedestrian safety across the five signalized intersections studied. These measures—Time-to-Collision (TTC), Post-Encroachment Time (PET), and conflict rates—were used to assess the risk of pedestrian-vehicle interactions.

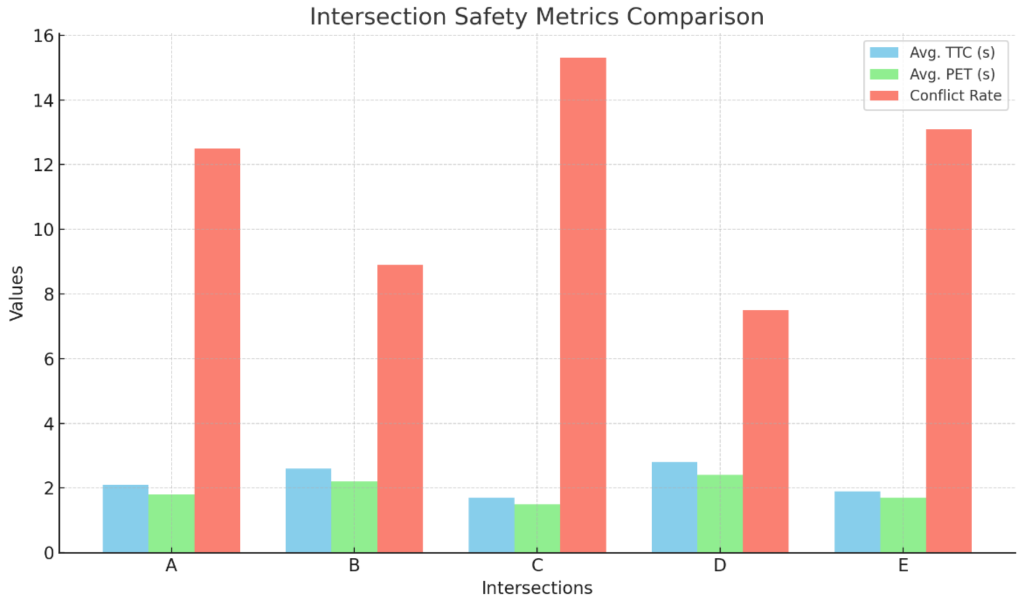

Figure 1: Intersection safety Metrics comparison

- **Time-to-Collision (TTC)**

Time to Collision (TTC) is a key metric of pedestrian safety as it is the time to collision when the pedestrian and the vehicle are assumed to continue with the same speed. Achieving the highest average TTC (2.8 seconds) at Intersection D implied that pedestrian generally had enough time to avoid the collision, which had something to do with longer pedestrian signal phase or lower vehicle speed. On the other hand, average TTC of intersection C (1.7) was the lowest and indicated that pedestrian's risk of potential conflict with vehicles was higher since vehicle approached closer or at higher speed.

- **Post-Encroachment Time (PET)**

Post Encroachment Time (PET) represents the interval from the time a pedestrian clears the zone of a possible conflict through the time a vehicle enters the same space. The highest value for PET was for Intersection D (2.4 s), indicating that in most cases pedestrians had time to cross the crossing before arriving vehicles came. This suggests safer pedestrian conditions. However, Intersection C had the lowest PET (1.5 sec.), indicating that pedestrians were often in the proximity of vehicles when entering or crossing the intersection increasing the risk of conflict.

Table 1: Descriptive Statistics of SSMs

Intersection	**Avg. TTC (s)**	**Avg. PET (s)**	**Conflict Rate (per 1000 crossings)**
DM chowk Noida **(A)**	2.1	1.8	12.5
Sector 21 Junction (At Modi Mall) **(B)**	2.6	2.2	8.9
Sector 58 Junction **(C)**	1.7	1.5	15.3
Sector 62 Junction **(D)**	2.8	2.4	7.5
Sector-12 Junction (at Noida Stadium) **(E)**	1.9	1.7	13.1

- **Conflict Rate**

An indication of the conflict rate, i.e. the number of near miss events between pedestrians and vehicles per 1000 pedestrian crossings, is a direct measure of the frequency of unsafe interactions between pedestrians and vehicles. The conflict rate by intersection C was (15.3 per 1000) and this is a high conflict rate, this shows that it is the most dangerous intersection for pedestrians. The high traffic volume and the selected geometric design probably were factors in this elevated risk. As such, Intersection D (the lowest rate of conflicts at 7.5 per 1000 crossings), with a favorable pedestrian signal timing and lower vehicle speeds is likely present in the safest conditions.

4.2. Conflict Severity Distribution

The probability distributions of the conflict severity at the five study intersections exhibit large differences in pedestrian-vehicle interaction risks. The percentage of high, moderate, and low severity conflicts is given in Table 4.2, and Intersection C has the highest percentage of high severity conflicts (33 per cent) amongst all sites in Table 2. As compared to Intersection D, which recorded the least proportion of high severity conflicts, only 15%.

- **High-Severity Conflicts**

Pedestrian's situation in imminent or near collision conflicts is quite severe and high severity. Several factors contribute to the 33% of high severity conflicts at intersection C. It is at such an intersection situated within a high traffic area with wide foot traffic, making it so that pedestrians often are forced to be in the crosswalk for longer, increasing the chances of a conflict with cars. Moreover, due to the signal phasing at Intersection C, the probability for pedestrian crossovers to occur at time intervals that provide sufficient time for vehicle flow increases during peak vehicle volume. For example, Intersection D on a 15% high severity conflicts recorded, seems to benefit more from more optimized pedestrian signal timings with longer green pedestrian intervals allowing more time for pedestrians to cross safely with vehicles not in their path.

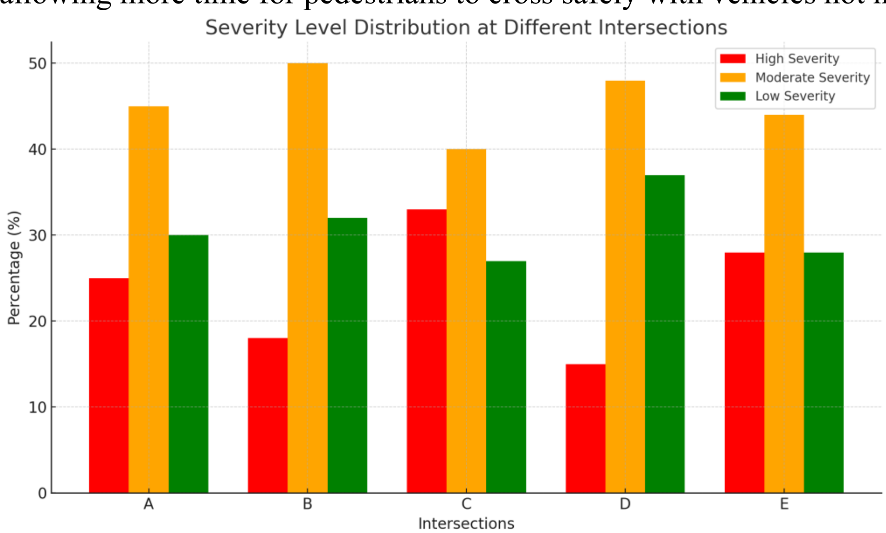

Figure 2: Severity Level Distribution at Different Intersections

- **Moderate-Severity Conflicts**

While not the most dangerous situations (high-severity), moderate-severity conflicts, caused by a significant risk of injury. However, these conflicts occur, when the vehicles and pedestrians were very close to each other without a collision. It was observed that the moderate severity category had relatively balanced distributions at all of the intersections with percentages between 40% and 50%. Intersection B, the one with the most complicated geometry, showed the highest percentage (50%) of moderate severity conflicts, perhaps because more pedestrian vehicle interactions do not mean that there are more conflicts at greater risk.

- **Low-Severity Conflicts**

Intersections D and E showed the highest percentages of 37 and 32 for the low severity conflicts, where pedestrians and vehicles held a safe distance from each other. It is likely that these intersections are pedestrian friendly with pedestrian phases in which pedestrians have less time crossing and vehicles have minimum space to overtake pedestrians.

Table 2: Conflict Severity Distribution

Severity Level	**DM chowk Noida (A)**	**Sector 21 Junction (At Modi Mall) (B)**	**Sector 58 Junction (C)**	**Sector 62 Junction (D)**	**Sector-12 Junction (at Noida Stadium) (E)**
High	25%	18%	33%	15%	28%
Moderate	45%	50%	40%	48%	44%
Low	30%	32%	27%	37%	28%

Conflict severity is distributed between intersections, which indicates the uneven pedestrian safety risks. These intersections having higher proportions of high severity conflicts, such as Intersection C, are indicative of an intervention likely, such as a signal adjustment, geometric modification or improved pedestrian facilities, to mitigate these risks. Turning this around, intersections with more low severity conflicts, such as Intersection D, might be used as models of good practices in pedestrian safety, highlighting the efficacy of certain traffic control daycare that have more moderate severity conflicts.

4.3. Comparison with Historical Crash Data

The comparison with pedestrian crash data for the same period revealed strong correlation between the two, which confirms that SSMs may be used as a surrogate for predictive safety of pedestrian at signalized intersections. The five year comparison of number of crashes at each intersection and cluster of risk categories based on SSM is provided for comparison in. SSMs also classified Intersection C (which had the highest number of crashes, 18, for pedestrian crashes) as 'High' risk. TTC values in this intersection had the least values, which means that pedestrians and vehicles collided with each other frequently, which makes sense since they speak of a high risk reflected by historical data.

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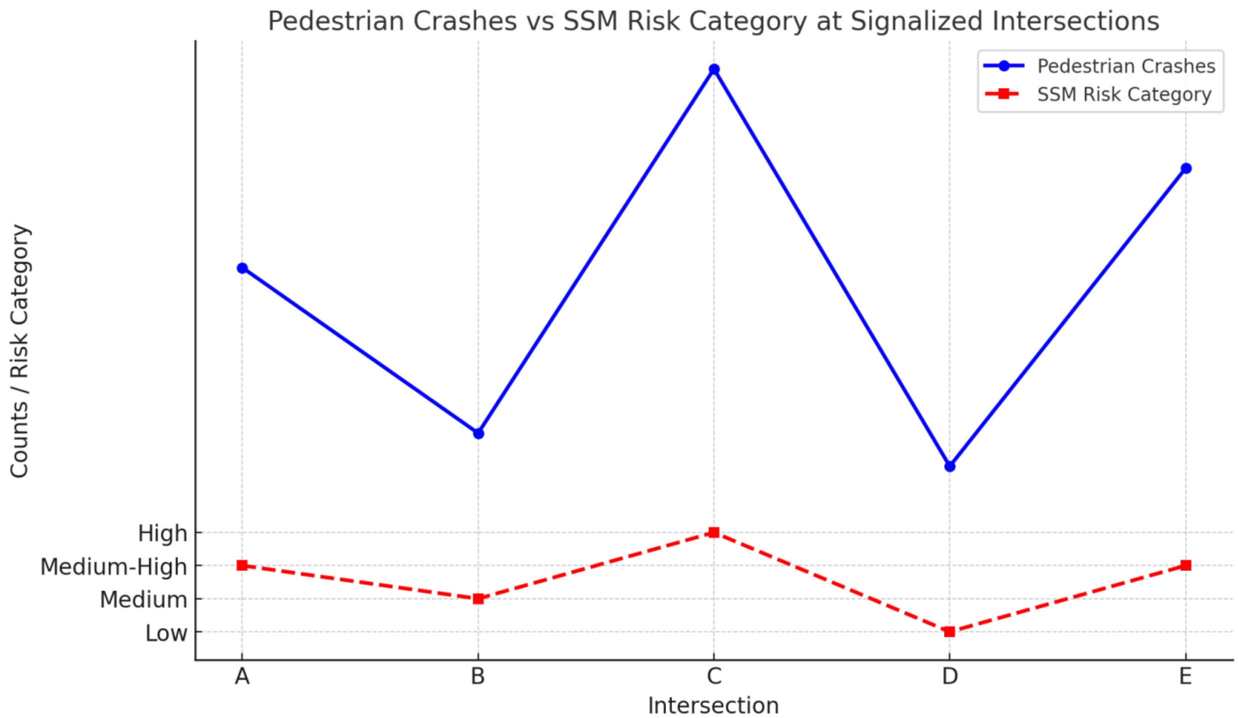

Figure 3: Pedestrian Crashes and the SSM Risk Categories for Each Intersection

Comparison of SSMs to historical pedestrian crash data showed a strong correlation between the two that validated SSMs as a predictive tool for pedestrian safety at signalized intersections. By listing crashes at all intersections for a five year period and corresponding risks to each intersection based on SSM, Table 1 presents the number of pedestrian crashes. SMs showed that the Intersection C, which had the highest number of pedestrian crashes (18 crashes) was also “High” risk based on SSMs. Time to Collision (TTC) values obtained at this intersection were the most frequently recorded near collisions among pedestrians and viConversely, Intersection with only 6 recorded pedestrian crashes within the same span was ranked as "Low" risk in terms of SSMs. At this intersection, TTC and Post-Encroachment Time values were higher indicating safer conditions for pedestrians. In addition, Intersections A and E with 12 and 15 pedestrian crashes had been classified as `Medium-High' risk by SSMs, which was consistent with moderate to high crash frequencies observed in historical data.

A significance of SSM based risk categories vs actual pedestrian crash data has been calculated a Pearson based correlation coefficient of 0.82. It is this that indicates that operative surrogate measures do capture actual pedestrian risk levels in these intersections. Since SSMs can be used to predict pedestrian safety, it is a feasible way to do proactive traffic management without accidents occurring beforehand. As suggested by this finding, surrogate measures are a relevant and useful component of pedestrian safety evaluation in urban environments.

Table 3: Comparison with Historical Crash Data

Intersection	5-Year Pedestrian Crashes	SSMs Risk Category

DM chowk Noida **(A)**	12	Medium-High
Sector 21 Junction (At Modi Mall) **(B)**	7	Medium
Sector 58 Junction **(C)**	18	High
Sector 62 Junction **(D)**	6	Low
Sector-12 Junction (at Noida Stadium) **(E)**	15	Medium-High

There was a strong correlation (r = 0.82) between the computed SSM-based risk category and historical crash data, validating the use of SSMs.

5. Discussion

5.1. Influence of Intersection Design

Pedestrian safety depends largely on the way an intersection is designed, primarily in terms of crossing distance, traffic volume and phasing of signals. There are different levels of risk in terms of the effect of intersection design both geometric features and operational aspects onto pedestrian movement. The study showed that the intersections undoubtedly experienced higher conflict rates when the pedestrian crossing distance and signal phase were shorter, meaning that they prone themselves to be more vulnerable to the pedestrians. One of the prime examples of such a trend is Intersection C where the road was over 40 meters wide, and at such a colossal road and crossing distance for pedestrians. For example, there is an average pedestrian crossing time of 20 seconds at this intersection, not enough time for many pedestrians to safely cross, especially given the average speed of pedestrians. Pedestrians were, as a result of this situation, placed in a potentially dangerous situation in which they had to rush across the street or remained in objection's path during red lights. In this instance, the conflict rate was also high, there were more chances for pedestrians to be struck by the vehicles, as the geometry of the intersection was cold.

Sector-12 Junction (at Noida Stadium)

Sector 62 Junction

Sector 58 Junction

Sector 21 Junction (At Modi Mall)

DM Chowk Noida

Figure 4: Urban planner junctions with large crossing distances

Wherever the distance of the crosswalk is less than the distance of the intersection, larger signal phases are often needed to allow pedestrians enough time to walk across the crosswalk. However, if signal phases are not adjusted with pedestrians, as with signal phases, pedestrians only have a little time to cross, especially during peak traffic hours and, therefore, when the road is congested or traffic flows at its highest. The occurrence of pedestrian accidents as the pedestrians do not finish crossing the road within the time allocated reduces drastically as everyone who finishes crossing the road before the exit time can cross the road easily and continue their journey. Therefore, it is critical to the right of pedestrian movement across the street, that the intersection be properly designed. The longer the road is the longer pedestrians are exposed to a potential conflict with motor vehicles. In addition, road widths more than 30 meters can enhance the chance that pedestrians will have to make their way through multiple lanes, notably while they cross big arterial roads. Here, pedestrian delay times rise and we have a scenario where pedestrians decide to cross when the signal is turning yellow or red, thus deteriorating the potential for conflict. Therefore, the urban planners need to redesign the junctions (figure 4, and figure 5) with large crossing distances by reducing the width of the roads or increase the duration of signal phases in order to accommodate the pedestrian movement.

Figure 5: Urban planner Sector-62 Junction

5.2. Signal Timing and Pedestrian Behavior

The influences of the signal timing are one of the most important determinant factors in pedestrian safety at signalized intersections. In this case, the important factor is the duration of the pedestrian clearance intervals to prevent conflicts. It turned out that high severity conflicts increased significantly at intersections that had a pedestrian cleared interval of less than five seconds. In addition, when pedestrians believe they will be able, in fact, to make it across the road before the signal changes, short pedestrian clearance times may cause pedestrians to take risks. It is this behavior that leads pedestrians to attempt to cross streets during the late yellow or start of the red cycle of the stoplight, which often places vehicles in their accelerator or close enough position.

During signal changes, pedestrians tend to face a dilemma. When they see the signal becoming yellow they might get the impulse to rush even if that is dangerous because they think their time to cross is ending. But this is something that came from urban areas with time pressure and big traffic volumes the 'hurry up' mentality. This behavior can cause people to be stuck in the roadway during the red phase or halfway across when turned green if the pedestrian clearance interval is too short. While longer pedestrian clearance intervals give pedestrians more time to cross safely, they are less likely to have high severity conflicts.

To improve awareness, it was observed that many pedestrians would begin crossing at intersections where clearance times were found to be especially brief and as a result, would be midsentence when the signal turned red. It magnifies the threat of vehicle-pedestrian crash, particularly at locations where vehicles are turning or accelerating from a red light. Additionally, it is more likely for there to be conflict when pedestrians are in the crosswalk at the transition period because drivers may not expect to see pedestrians crossing when signal visibility or awareness are insufficient. These issues must be mitigated by altering the signal timing. An increase in pedestrian clearance time in high volume pedestrian area can contribute in reducing risky pedestrian action. A further improvement in safety would be to implement leading pedestrian intervals (LPIs), in which pedestrians have priority over turning vehicles. Changes in signal timing in these small degrees can significantly affect the number of pedestrian associated accidents.

6. Conclusion

This study supports the use of SSM as essential tool for pedestrian safety around signalized intersections. High conflict rates in particular, and particularly high severity rates, correlated well with historical pedestrian crash data. Locations with lower Time-to-Collision (TTC) and shorter Post-Encroachment Times (PET) had more pedestrian crashes in historical data, corresponding with higher levels of conflict as indicated by lower TTC and shorter PET at intersections. This supports the notion that surrogate measures can be reliable, real-time indicators of pedestrian risk in use of data that are perhaps not reflected in catastrophic data due to the low frequency of the pedestrian fatalities. The results are used to propose several recommendations for improving the pedestrian safety at signalized intersections. First, as a means of increasing pedestrian signal phase times, it is possible to increase signal phase times at intersections with wide crossings to give pedestrians enough time to cross safely. Secondly, leading pedestrian intervals (LPIs) can initiate for cyclists and pedestrians when vehicles are not about to start moving, thereby reducing conflicts. Third, reducing pedestrian crossing distances by reconfiguring the intersection geometry will decrease the exposure to potential vehicle conflicts. This helps in finally incorporating SSM based evaluations into routine traffic safety audits and therefore identify some high risk intersections that can be acted upon at an early time even before any occurrence of the accident. Further research should be conducted to expand the United States of America scope of analysis to include conditions other than those of full daylight in familiar urban areas with no adverse weather. Moreover, the use of machine learning techniques for machine automatic conflict detection and severity prediction have great potentials.

There are certain limitations of using SSM in judging pedestrian safety at places with traffic signals. Manufacturers often use simulations or modeled data in SSMs, which can make these cars unsuitable to react to sudden changes or distractions caused by drivers. People walking often cross the street in red lights or stop in the middle of a crossing, something SSMs do not usually notice. Collecting real pedestrian actions at crossings can help ensure the findings are more valid and important. Finding solutions for these problems can lead to a better understanding of how pedestrians can stay safe in busy urban streets. Future studies will be able to improve real time safety assessments and achieve a greater level of efficiencies with identifying areas that need improvement in safety. Also, having diverse intersection types and geographical regions could reveal a more holistic impression of pedestrian safety in varied urban contexts.

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