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Video-Based Study of Pedestrian Compliance at Signalized and Non-Signalised Crossings in Athens

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Abstract

Vulnerable road users (VRUs) and their safety are a vital pillar of the Safe System approach and achieving Vision Zero objectives. This research examines pedestrian behaviour and violation patterns at both signalised and non-signalised intersections in the city centre of Athens, Greece, using video data recordings captured on mounted tripods with mobile phone cameras and computer vision algorithms as part of the PHOEBE project. The objective is to quantify compliance levels and identify the environmental, traffic, and behavioural factors influencing pedestrian crossing decisions.

Video data were collected from two intersections in the center of Athens representing diverse traffic conditions, geometric layouts, and pedestrian demand levels. Using advanced computer vision and machine learning methods, pedestrian and vehicle movements were automatically detected, classified, and tracked. The analytical framework combined YOLOv8 for object detection, a Kalman filter for trajectory tracking, and a homography transformation for real world coordinates. The resulting dataset included detailed temporal and spatial features such as crossing duration, traffic light phase for the signalized crossing, pedestrian speed, and vehicle proximity. Each crossing event was automatically labelled as compliant or non-compliant according to the prevailing traffic signal and safety conditions.

Subsequent statistical and data-driven modelling was conducted to determine the predictors of non-compliance. Logistic regression and Poisson regression models were applied to evaluate the influence of signal phase, vehicle flow, traffic speed, crossing width, and pedestrian characteristics on the likelihood and frequency of violations. The results reveal that compliance rates are significantly higher at signalised crossings compared with non-signalised ones. However, even at signalised locations, nearly one-third of pedestrians crossed during the red phase, particularly when perceived waiting times were long or vehicle approach speeds were low. In the case of the unsignalised crossings, violations were more frequent in smaller road segments and under conditions of moderate traffic flow or congested traffic flow, suggesting a behavioural trade-off between perceived risk and delay.

The results of the study offer practical insights for urban planners and road safety authorities. Some recommended actions include improving pedestrian visibility, lowering vehicle speeds near intersections, or optimizing signal timings. The study also demonstrates how automated video analytics can provide cost-effective, scalable data for evaluating pedestrian safety and monitoring compliance in real urban environments.

Keywords: Video analysis, Pedestrian Safety, Surrogate Measures of Safety, YOLO, Road Safety

1. Introduction

Road safety has become a major priority worldwide, particularly within the framework of the Safe System approach and Vision Zero strategies, which aim to eliminate fatalities and serious injuries on road networks (ITF, 2016). Within this context, vulnerable road users (VRUs), including pedestrians, cyclists, and motorcyclists, represent a critical group due to their increased exposure and lack of physical protection compared with vehicle occupants. Pedestrians in particular account for a significant proportion of road fatalities in urban areas, especially in dense city centres where interactions between vehicles and pedestrians are frequent and complex (World Health Organization, 2019).

One of the main safety concerns in urban environments is pedestrian crossing behaviour and compliance with traffic control devices. Pedestrians often choose to cross outside designated crossings or during the red signal phase when signalised crossings are available. Such violations are influenced by multiple factors, including waiting time, traffic flow, vehicle speed, road geometry, pedestrian characteristics, and social behaviour (Guo et al., 2011). Understanding these behavioural patterns is essential for designing safer urban environments and improving traffic management strategies.

Traditionally, pedestrian safety has been analysed using crash data. However, crash data are relatively rare events and often lack detailed information about pedestrian and vehicle trajectories before the crash occurs. For this reason, surrogate measures of safety (SMoS), such as Time to Collision (TTC) and Post Encroachment Time (PET), have been increasingly used to evaluate safety conditions and traffic conflicts before crashes occur (Tarko, 2012; Laureshyn et al., 2017). These indicators allow researchers to assess risk levels and identify dangerous interactions even when no crash has taken place.

In recent years, advances in computer vision and machine learning have enabled automated extraction of pedestrian and vehicle trajectories from video recordings. Object detection algorithms, tracking methods, and trajectory reconstruction techniques allow the estimation of speeds, distances, interactions, and surrogate safety indicators (Ismail et al., 2009; Saunier & Sayed, 2010; Ziakopoulos & Yannis, 2020). These technologies provide a cost-effective and scalable method for collecting detailed behavioural and safety data in real urban environments.

Despite the growing number of studies on pedestrian behaviour and traffic conflicts, limited research has combined automated video analytics, trajectory-based surrogate safety indicators, and behavioural modelling to compare pedestrian behaviour and safety conditions between signalised and non-signalised crossings under real urban conditions. Therefore, the aim of this study is to investigate pedestrian behaviour, compliance patterns, and safety conditions at signalised and non-signalised crossings in the city centre of Athens using automated video analytics and trajectory-based surrogate safety indicators.

2. Literature Review

2.1. Pedestrian Behaviour at Crossings

Pedestrian behaviour at urban crossings has been widely studied, particularly in relation to compliance with traffic signals and crossing decisions. Research has also demonstrated that pedestrians have been known to violate traffic signals due to long waiting times, low traffic flow, or the perception that they can complete the crossing safely prior to the arrival of approaching vehicles (Guo et al., 2011; Yannis et al., 2013). Social factors have also been found to influence pedestrians, with pedestrians more likely to cross illegally where other pedestrians are also crossing or where they are in groups (Papadimitriou et al., 2009).

Age and mobility characteristics also influence pedestrian behaviour. Younger pedestrians have been found to have higher risk acceptance higher violation rates. On the other hand, older pedestrians are found to display more conservative behaviour, although they may need longer crossing times because of their slower walking speed. Dommes et al. (2012) found that environmental factors such as crossing width, visibility, bus stops, and land use also influence pedestrian crossing behaviour.

At non-signalised crossings, pedestrian behaviour is often influenced by gap acceptance, vehicle speed, and driver yielding behaviour. Pedestrians tend to cross when acceptable gaps in traffic are available, but the perception of acceptable gap size varies significantly among individuals and traffic conditions (Papadimitriou et al., 2009). This behaviour creates complex interactions between pedestrians and vehicles, which may result in traffic conflicts and unsafe situations.

2.2. Surrogate Safety Measures

Because crash data are limited and do not capture near-miss events or risky interactions, surrogate safety measures have been increasingly used in traffic safety research. Surrogate safety measures quantify the level of risk during interactions between road users and allow proactive safety assessment without relying solely on crash data (Tarko, 2012; Laureshyn et al., 2017).

The two most frequently used surrogate safety metrics are Time to Collision (TTC) and Post Encroachment Time (PET). TTC refers to the remaining time until collision between two road users in the event that they continue with their present speed and course. On the other hand, PET refers to the time difference between a road user clearing a conflict point and another road user arriving at the same point (Laureshyn et al., 2017). Lower values of TTC and PET correspond to higher levels of risk.

It has been established in earlier research that values of TTC less than 3 seconds and PET less than 1 second are associated with risky interactions or near-crash situations (Ziakopoulos & Yannis, 2020; Laureshyn et al., 2017). Furthermore, surrogate measures can detect hazardous conditions and safety risks in advance to prevent accidents, and can contribute towards road safety measures.

2.3. Video Analytics and Trajectory Extraction

The development of computer vision and machine learning techniques has significantly improved the ability to analyse traffic behaviour using video data. Modern object detection algorithms allow accurate detection of pedestrians and vehicles in video frames, while tracking algorithms allow the reconstruction of trajectories over time (Ismail et al., 2009; Saunier & Sayed, 2010).

By combining object detection, tracking algorithms, and camera calibration techniques such as homography transformation, it is possible to convert image coordinates into real-world coordinates and compute speeds, accelerations, distances, and interaction indicators. These trajectory-based datasets enable the calculation of surrogate safety indicators such as TTC and PET and allow detailed analysis of pedestrian and vehicle interactions.

Automated video analysis has several advantages compared with traditional manual observation methods. It reduces human error, allows the processing of large datasets, and provides detailed trajectory data that cannot be obtained from crash databases or traditional traffic counts. As a result, video analytics has become an important tool for traffic safety analysis and behavioural studies in urban environments. Recent studies have further demonstrated the potential of trajectory-based video analytics and machine learning techniques for the identification and prediction of pedestrian–vehicle conflicts in urban environments (Zhang et al., 2020).

3. Study Sites and Data Collection

3.1. Study Sites

The study site is located in the city centre of Athens in Greece, at the Panepistimiou and Vasilissis Sofias Avenue. There are two study areas where the crossing environment is different: one is a signalised intersection and the other is a non-signalised crossing area. These areas were selected for the study because of the large number of pedestrians using the areas, the presence of public transport stops, mixed land use, and the large number of pedestrian-vehicle interactions.

The signalised crossing area was selected for the study because of the location of the intersection in the central area of Athens. This is where pedestrians are facilitated in crossing the road using the traffic signal and the pedestrian signal phase. This area has a large number of traffic movements, two lanes, the presence of public transport stops, commercial land use, and a large number of pedestrians crossing the road.

The non-signalised location is located a few meters away from the first location where pedestrians frequently cross the road without traffic signal control as they want to catch the bus or due to the fact that the next designated crossing area is many meters away. The area includes commercial activities, pedestrian flows, and vehicle traffic with moderate speeds. In this case, pedestrian crossing behaviour is mainly influenced by gap acceptance, vehicle flow, and perceived risk rather than signal control.

The two sites were selected in order to compare pedestrian behaviour and safety conditions under controlled and uncontrolled crossing environments within similar urban conditions. For clarity, the signalised crossing location is hereafter referred to as the "Signalised Crossing Site", while the uncontrolled pedestrian crossing location is referred to as the "Non-Signalised Crossing Site".

3.2. Video Data Collection

Video recordings were collected during June 2024 on Tuesdays and Thursdays over a one-month period, covering both peak-hour and off-peak-hour traffic conditions. The recordings were captured using an iPhone 11 Pro Max mounted on a tripod and positioned at elevated locations to ensure clear visibility of the crossing areas and traffic movements. The cameras were placed in positions that allowed the recording of both pedestrian and vehicle trajectories within the interaction area while minimizing occlusions.

The recordings were conducted during peak traffic periods in order to capture a sufficient number of pedestrian crossings and vehicle interactions. The video recordings were captured at approximately 29.47 frames per second, allowing detailed trajectory extraction and interaction analysis. The recorded videos included pedestrian movements, vehicle movements, traffic signal phases (for the signalised site), and interactions between pedestrians and vehicles within the crossing area.

3.3. Computer Vision Processing and Trajectory Extraction

The recorded videos were processed using computer vision and machine learning algorithms in order to automatically detect, classify, and track pedestrians and vehicles. The processing pipeline included object detection, trajectory tracking, and coordinate transformation (Ventura et al., 2025).

Object detection was performed using the YOLOv8 algorithm, which was used to detect pedestrians and vehicles in each video frame. A Kalman filter tracking algorithm was then applied to track detected objects across frames and reconstruct continuous trajectories for each pedestrian and vehicle. To convert image coordinates into real-world coordinates, a homography transformation was applied using reference points from the road geometry.

Using the reconstructed trajectories, several movement and interaction variables were calculated, including pedestrian speed, crossing duration, vehicle speed, distance between pedestrians and vehicles, Time to Collision (TTC), and Post Encroachment Time (PET). These variables were used to analyse pedestrian behaviour and safety conditions at the two study sites.

3.4. Interaction and Behaviour Dataset

The final dataset consisted of pedestrian crossing events and pedestrian-vehicle interaction events. For each crossing event, variables such as crossing duration, pedestrian speed, traffic signal phase (for the signalised site), and compliance behaviour were recorded. Each crossing event was classified as compliant or non-compliant depending on whether the pedestrian crossed during the permitted phase or outside designated crossing conditions.

For each interaction event between pedestrians and vehicles, surrogate safety indicators were calculated, including minimum TTC and minimum PET values. For each interaction event between pedestrians and vehicles, surrogate safety indicators were calculated, including minimum TTC and minimum PET values. These indicators were used to identify critical interactions and compare safety conditions between the signalised and non-signalised locations. These indicators were used to identify critical interactions and compare safety conditions between the signalised and non-signalised locations.

The resulting dataset allowed both behavioural analysis (compliance and violations) and safety analysis (traffic conflicts and surrogate safety indicators), enabling a comprehensive comparison between signalised and non-signalised pedestrian crossings.

4. Data Analysis

4.1. Pedestrian–Vehicle Interaction Severity at Signalised Crossing

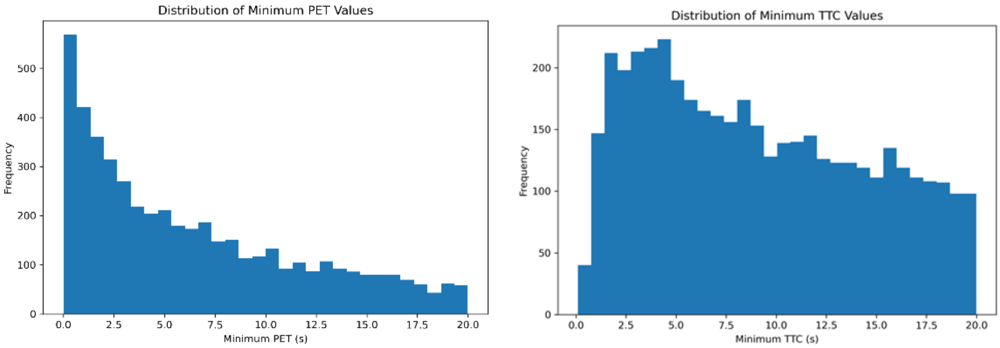
The analysis of pedestrian-vehicle interactions at the Signalised Crossing Site was conducted using surrogate safety measures, specifically Time-to-Collision (TTC) and Post-Encroachment Time (PET). These indicators were calculated for each interaction event in order to assess interaction severity and identify potentially critical conflicts.

Table 1 presents the descriptive statistics of the minimum TTC and minimum PET values observed at the study location. The results indicate that TTC and PET values cover a wide range of interaction conditions, from safe interactions with large temporal margins to more critical interactions with low TTC and PET values.

Table 1. Descriptive statistics TTC & PET

Indicator	Mean	Median	Std	Min	Max	P_{25}	P_{75}
Minimum TTC (s)	9,057	8,370	5,470	0,095	19,990	4,292	13,565
Minimum PET (s)	6,373	4,895	5,416	0,001	19,994	1,723	10,083

The distribution of TTC values showed that most interactions occurred under relatively safe conditions, with high TTC values. However, a considerable number of interactions presented low TTC values, indicating the presence of potentially critical pedestrian-vehicle conflicts at the study site. A similar pattern was observed for PET values, where most interactions were associated with relatively high PET values, but a number of interactions presented low PET values, indicating limited temporal separation between pedestrians and vehicles.



(a) (b)

Fig. 1. Distribution of Minimum (a) PET values; (b) TTC values.

To further investigate interaction severity, threshold values were applied. Interactions with TTC values below 3 seconds and PET values below 1 second were considered critical or potentially dangerous interactions. The threshold analysis indicated that a noticeable proportion of interactions fell below these thresholds, suggesting that critical pedestrian-vehicle interactions occur at the examined location.

Table 2. Threshold analysis

Metric	Percentage	Metric	Percentage
TTC_lt_5	30.537	PET_lt_2	27.729

TTC_lt_3	15.280	PET_lt_1	16.276
TTC_lt_1_5	4.825	PET_lt_0	9.277
TTC_lt_1	1.907		

In addition, interactions were classified into severity categories based on TTC and PET values (high, medium, low, safe). The results showed that although the majority of interactions were classified as safe, a significant number of interactions fell into the medium and high severity categories, indicating the presence of potentially dangerous pedestrian-vehicle interactions at the study site.

Table 3. Severity Categories TTC & PET

TTC Category	Count	Percentage	PET Category	Count	Percentage
Safe	3023	69.462	Safe	3521	72.27
Low	664	15.257	Low	558	11.45
Medium	455	10.454	Medium	452	9.27
High	210	4.825	High	341.6	6.99

The relationship between TTC and PET was also examined. The results showed that TTC and PET are related but capture different aspects of interaction severity. While TTC reflects the potential for collision based on relative speed and distance, PET represents the temporal separation between road users at the conflict point. Therefore, the combined use of TTC and PET provides a more comprehensive assessment of pedestrian-vehicle interaction severity.

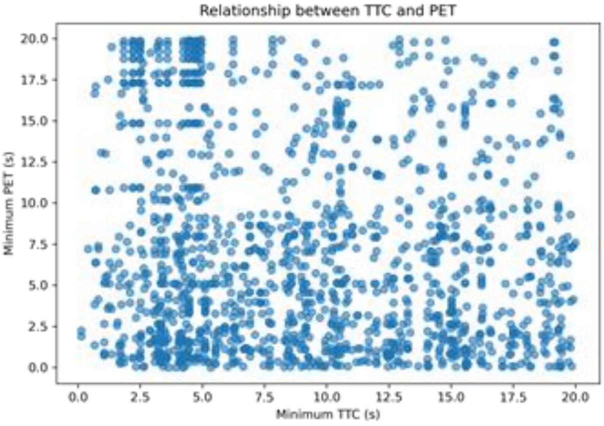


Fig. 2. TTC vs PET scatter

Furthermore, the temporal distribution of critical interactions showed variability over time, indicating that interaction severity is not constant but depends on traffic and pedestrian flow conditions during different time periods.

Overall, the results for the Signalised Crossing Site indicate that although most interactions are relatively safe, a significant number of potentially critical interactions occur. Interaction severity appears to be influenced by vehicle speed and the spatial location of the interaction, particularly for interactions occurring outside the signalised crossing area, which tend to present lower TTC values and therefore higher conflict severity.

4.2. Pedestrian–Vehicle Interaction Severity at Non-Signalised Crossing

The pedestrian-vehicle interactions at the Non-Signalised Crossing Site were analysed using event-level surrogate safety indicators, focusing primarily on Post-Encroachment Time (PET). The analysis identified a total of 18 interaction events, and the descriptive statistics indicated substantially lower PET values compared with the Signalised Crossing Site. The median minimum PET value was 0.89 s, indicating very limited temporal separation between pedestrians and vehicles at the conflict point. Several interactions presented extremely low PET values, reflecting situations where pedestrians crossed in close temporal proximity to approaching vehicles.

Threshold analysis further confirmed the severity of interactions at the non- signalised crossing area. Specifically, 50.0% of interaction events presented PET values below 1s, while 37.5% of events presented PET values below 0.5 s. These results suggest that a considerable proportion of pedestrian crossings at the Non-Signalised Crossing Site occur under highly constrained temporal conditions, indicating potentially critical interaction situations.

From a behavioural perspective, the interaction patterns at the Non-Signalised Crossing Site appear to be primarily influenced by pedestrian gap acceptance behaviour rather than signal control. The analysed interaction events suggest that pedestrians may accept shorter temporal clearances at the examined Non-Signalised Crossing Site; however, the limited sample size warrants cautious interpretation of these findings.

4.3. Comparative Analysis Between Signalised and Non- Signalised Crossing Areas

A comparative analysis was conducted in order to examine the differences in pedestrian-vehicle interaction severity between the Signalised Crossing Site and the Non-Signalised Crossing Site. The comparison was primarily based on event-level minimum PET values and the proportion of critical interactions.

The results indicate clear differences in interaction severity between the two crossing environments. The signalised crossing presented substantially higher minimum PET values, with a median minimum PET of approximately 6.20s, indicating relatively comfortable temporal separation between pedestrians and vehicles. In contrast, the Non-Signalised Crossing Site presented a median minimum PET of only 0.89 s, indicating significantly narrower temporal safety margins.

The threshold analysis further highlighted these differences. At the Signalised Crossing Site, only 5.9% of interaction events presented PET values below 1s and 5.9% below 0.5s. In contrast, at the Non-Signalised Crossing Site, 50.0% of events presented PET values below 1s and 37.5% below 0.5s. These results clearly indicate that critical pedestrian–vehicle interactions occur much more frequently at the Non-Signalised Crossing Site.

The statistical comparison using the Mann-Whitney test showed a statistically significant difference in minimum PET values between the two crossing types, confirming that the observed differences in interaction severity are not due to random variation.

Overall, the analysis showed that pedestrian-vehicle interaction severity differs considerably between the Signalised Crossing Site and the Non-Signalised Crossing Site. While the Signalised Crossing Site generally presented larger temporal safety margins and more structured interactions, the Non-Signalised Crossing Site was associated with substantially lower PET values and a higher proportion of critical interactions. The findings observed at the examined locations indicate that crossing infrastructure and traffic control conditions may influence pedestrian–vehicle interaction characteristics, although additional data from a larger number of interaction events would be required to support broader conclusions. The use of surrogate safety measures allowed the identification of critical interaction patterns that may not be visible through crash data alone.

5. Conclusions

This study investigated pedestrian-vehicle interaction severity at a Signalised Crossing Site and at a Non-Signalised Crossing Site using surrogate safety measures, specifically TTC and PET. The analysis was based on event-level interaction indicators in order to identify critical interactions and compare safety conditions between different crossing environments.

The results showed that although most interactions at the signalised crossing occurred under relatively safe conditions, a number of interactions presented low TTC and PET values, indicating the presence of potentially critical pedestrian-vehicle conflicts. The Non-Signalised Crossing Site presented substantially lower PET values and a significantly higher proportion of critical interactions, suggesting more constrained temporal safety margins and more opportunistic pedestrian behaviour.

The comparative analysis confirmed that interaction severity differs between Signalised Crossing Site and Non-Signalised Crossing Site environments. Signalised crossings appear to provide more structured interaction conditions and larger temporal separation between pedestrians and vehicles, while non-signalised crossings are associated with gap-acceptance behaviour and a higher likelihood of critical interactions. The findings also contribute to a better understanding of pedestrian compliance behaviour under different crossing environments and traffic control conditions.

In addition to the surrogate safety analysis, the study considered pedestrian compliance and violation patterns across various types of crossing situations. The results of the behavioural analysis helped identify the parameters linked to non-compliance while crossing the street and contributed to enhancing the knowledge on the decision-making process among pedestrians.

Overall, the study demonstrates the usefulness of surrogate safety measures for evaluating pedestrian safety conditions and identifying critical interaction patterns in urban environments. The methodology can support proactive road safety assessment and the evaluation of pedestrian crossing conditions, especially in locations where crash data are limited. Additionally, re-examining the locations needed to either provide a traffic light where needed or signalised crossing area has substantially importance to the Vision Zero goal.

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