Video-Based Analysis of Pedestrian Behaviour in Contrasting Greek Urban Environments Using Smartphone Cameras

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Abstract. Pedestrian safety remains a major challenge in densely populated urban areas and in touristic regions, where traffic dynamics and human behavior vary significantly. In Greece, both the center of Athens and popular tourist destinations across the country experience increased risks for vulnerable road users, especially at signalized intersections. This study investigates pedestrian non-compliance at two locations with contrasting urban characteristics. The one is a signalized intersection near Syntagma Square in the center of Athens, and one in Rethymno, Crete, a highly touristic city. Data collection was performed using video recordings from smartphone cameras, demonstrating a low-cost and flexible approach for urban traffic monitoring. Video data were processed through an advanced computer vision algorithm, structured in the context of the Phoebe Project, integrating YOLOv8, ResNet-50, homography transformation, and Kalman filtering, obtaining precise tracking of pedestrian and vehicle trajectories. Comparative analysis between the two locations illustrates the differences in non-compliant pedestrian behavior induced by the effect of urban density and tourism-related factors. The conclusions of this study enlighten pedestrian safety concerns in several Greek urban spaces and reveal the potential of video recognition algorithms to aid road safety research.

Keywords: Pedestrian behavior, Video-Based Analysis, Urban Environments, Vulnerable Road Users, Road Safety.

1 Introduction

In cities all over the world, pedestrian safety represents an important issue. Each year, a number of people lose their lives in road crashes, and unfortunately, the highest number has been concentrated in the densely populated urban environments [12]. As the most vulnerable road users, pedestrians are at a high risk of collision, especially under conditions of non-compliant crossing behaviour. This key factor contributing to the problem includes behaviors such as crossing outside designated facilities, ignoring traffic signals, or engaging in jaywalking [1]. Understanding these behaviors and quantifying their associated safety risks is vital for designing effective interventions and improving urban safety.

Jaywalking is commonly defined as crossing a street illegally or against traffic regulations, for example, entering the roadway during a red pedestrian signal, or crossing mid-block between intersections instead of using designated crosswalks [4]. Crossing outside designated areas refers specifically to pedestrians traversing the roadway at points without marked crosswalks, zebra crossings, overpasses, or pedestrian signals. People behave in that way, as they believe they will save time, avoid long waits, or make things more convenient, and although these actions may seem reasonable from the pedestrian's point of view, they make things riskier due to the lack of priority and predictability [10; 4].

Researchers use Surrogate Measures of Safety (SMoS) to investigate these behaviors [8], as they can measure risk without waiting for crashes to happen. Time to Collision (TTC) and Post Encroachment Time (PET) are two very important metrics, where TTC refers to the remaining time until a crash would happen if both users (vehicle with vehicle, or vehicle with pedestrian) keep moving at their current speeds and directions. PET measures the time gap between one road user leaving a potential conflict point and another entering it [5]. Another important factor is the gap acceptance, which is the smallest amount of space between vehicles that pedestrians are willing to cross. Other important factors are the time to cross, the waiting time before crossing, and how drivers yield [2]. Quantifying risk in illegal crossing situations and facilitating comparisons across various urban contexts demonstrate the importance of these metrics in these analyses.

In the European context, pedestrian protection is a central pillar of sustainable urban mobility policy [3]. Mediterranean countries, including Greece, face particular challenges due to dense city centers, fragmented infrastructure, and the significant role of tourism. Pedestrian behavior is complicated in the touristic regions as there is a mixture of residents and tourists, each group with different levels of familiarity with the road conditions and with a different road culture [7]. Having as an example, the center of Athens, where pedestrians have to confront the heavy traffic and the busy intersections. On the other hand, in touristic cities like Rethymno in Crete, pedestrian behavior is affected by seasonal needs, leisure activities, and mixed traffic situations. Analyzing these contexts provides substantial insights into the influence of urban density and tourism-related factors on pedestrian risk-taking and compliance [11].

Methodologically, the field has been transformed by computer vision and machine learning approaches. Traditional methods relied on manual observation and surveys, which are time-consuming and prone to bias [6]. Recent improvements, such as YOLO object detection, ResNet-based classification, and Kalman filtering, make it possible to automatically and accurately get the trajectories of people and vehicles from video [9]. Once they are mapped using methods like homography transformation, it is possible to calculate surrogate safety metrics (TTC, PET) on a large scale. This has allowed researchers to measure conflicts, check for compliance, and understand how well interventions work in different situations.

The present study enhances these methodological innovations by utilizing a cost-effective smartphone video collection technique, analyzed through a sophisticated computer vision pipeline established under the Phoebe Project (YOLOv8, ResNet-50, homography, Kalman filtering) [9]. The busy city center of Athens, which is highly dense in pedestrians and vehicles, and Rethymno, a very touristic city with different traffic patterns, are both examples of Greek cities. The study focuses primarily on non-designated crossings in both cities, while also utilizing designated crossings in Athens as a control group for comparison.

Following the introduction, the data collection sites are explained, as well as the video processing pipeline. Furthermore, the statistical analysis and comparative results are presented, as also the findings and their policy implications are discussed in the fourth section. The final section concludes with limitations and directions for future research.

2 Methodology

2.1 Study Sites

The data for this study were collected in two urban locations in Greece with distinct characteristics which don't represent the whole of Greece: the city center of Athens and the central district of Rethymno, Crete.

The Athens site is located at the intersection of Vasilissis Sofias Avenue and Irodou Attikou, a critical road segment near Syntagma Square. This area was selected because it represents a dense urban hotspot with continuous pedestrian flows, high vehicle volumes, and complex traffic interactions. Importantly, in proximity to the intersection (approximately 30-50 meters), several bus stops generate heavy pedestrian demand. Based on our field expertise, it has been consistently observed that a large proportion of pedestrians choose to cross the road at non-designated points, rather than waiting for the pedestrian signal at the designated crosswalk. This behavior is driven by the fact that the pedestrian signal cycle is perceived as excessively long, and because pedestrians often form the illusion that crossing diagonally across the avenue reduces overall travel time compared to walking toward and waiting at the regulated crosswalk.

The Rethymno site represents a different urban typology. It is a touristic hotspot located in the central shopping district, surrounded by retail outlets, restaurants, and attractions. While there are designated crossing facilities nearby, authorities have reported that many pedestrians regularly cross illegally at the selected site. As in Athens, this non-compliance is partially explained by the proximity of bus stops and the desire to minimize walking distance or waiting time. However, the pedestrian population in Rethymno also includes a high proportion of tourists, which further influences crossing behavior, as visitors may be less familiar with the local traffic rules and are often more focused on leisure activities.

2.2 Video data collection

At both sites, video recordings were collected using smartphone cameras. This approach was chosen because it has a low cost and it is flexible, which makes it good for use in real-world urban settings that need to be able to grow. In Athens, data collection had a duration of two hours, including both busy and off-peak hours, to have a good sample of how pedestrians and vehicles interact. In Rethymno, recordings were also made during hours when there was high pedestrian and vehicle traffic, with a focus on the area's touristic nature. All recordings were made at a frame rate of 29.74 frames per second, which made it possible to track trajectories in high resolution over time.

Computer vision pipeline & Surrogate safety measures

We used an advanced computer vision framework from the Phoebe Project to process the collected videos [9]. The pipeline is based on the object detection, YOLOv8 neural network, which tracks people and vehicles in each frame of the video. YOLOv8 can accurately understand and create a bounding box for the detected object. Following, ResNet-50 was integrated to correctly classify the detected objects and their identities from one frame to the next. We used homography transformation to put the pixel coordinates on the ground plane so that they could be used in the real world. The Hungarian algorithm was also used to match detections from different frames while keeping the object IDs the same. Finally, Kalman filtering was used to make the paths smoother and reduce the effect of noise in the detection.

In the Athens and Rethymno cases, the classification of illegal crossings did not depend on detecting the color of traffic lights. Instead, the region of interest (ROI) was defined to correspond to sections of the roadway outside the designated crossing facilities. Thus, any pedestrian crossing recorded within these ROIs was automatically considered illegal, as depicted in Figure 1. In this study, illegality was defined spatially, based on movement through a predefined ROI outside designated crossing facilities; therefore, signal-phase violations were not explicitly distinguished.

Fig. 1. Algorithmic Output at Vas. Amalias Av., Athens (a-left figure) & Kountouriotou street, Rethymno (b-right figure).

Once pedestrian and vehicle trajectories were extracted, Time to Collision (TTC) and Post Encroachment Time (PET), the two primary surrogate safety indicators, were calculated. Specifically, for each pedestrian-vehicle pair, TTC values were computed frame by frame. The calculation was based on the relative distance and velocity between the pedestrian and vehicle, as derived from Kalman-filtered real-world trajectories. Specifically, the distance between a pedestrian and an approaching vehicle was divided by their relative speed vector, yielding the time (in seconds) until a potential collision, assuming no change in movement.

Regarding the PET, it was computed to capture conflicts in which a pedestrian and a vehicle did not occupy the conflict point simultaneously but passed through sequentially. For each pedestrian-vehicle pair, the time difference between the pedestrian leaving the conflict zone and the vehicle entering it was calculated. Low PET values mean that the conflict is worse, while high PET values indicate that the interactions are safer.

These measures were chosen because they are well-known in the literature as good indicators of pedestrian safety at crossings, especially in studies where crash data is not available [8]. The selected PET and TTC thresholds were used as indicative severity bands based on commonly used values in the surrogate safety literature.

3 Results

After carefully watching the videos with a duration of one hour from both locations and analyzing them using the aforementioned computer-vision pipeline, we reported event-level surrogate safety metrics at these two Greek locations. For each event referring to jaywalking at a non-designated location, we identify the critical frame with the minimum Post-Encroachment Time (PET) or Time-to-Collision (TTC). In order to have a clean dataset, preprocessing of the data and exclusion of infinites (no pedestrian-vehicle interaction at the specific frame) were needed. This serves as a need to focus on the inference at the moment of greatest risk, rather than diluting it with non-critical frames. As context (not for inference), we used more or less than a 1-second window around each event, and approximately 30 frames, as the fps set of the algorithm was around 29.74.

Athens exhibits consistently short safety margins (n=22 events). The minimum PET has a median of 0.89 s (IQR 0.21-1.20), with 50.0% of events < 1.0 s and 37.5% < 0.5 s. These shares indicate that at least half of illegal crossings reached sub-second separations at the conflict point, and over one-third entered the very-high-risk PET (< 0.5 s). For minimum TTC, the median is 5.24 s (IQR 4.36-13.24), with 25.0% < 3.0 s and 50.0% < 5.0 s. Together, Table 1 depicts frequent near-conflicts at the point of closest approach, with multiple events crossing stringent risk thresholds.

Table 1. Event-level for Athens and Threshold shares for Athens.

Metric	**n (events)**	**Median(s)**	**IQR(s)**
MinPET	22	0.89	0.21-1.20
minTTC	22	5.24	4.36-13.24
Threshold		**Count**	**% of events**
PET < 0.5 s		8/22	36.4%
PET < 1.0 s		11/22	50.0%
TTC < 3.0 s		6/22	27.3%

TTC < 5.0 s	11/22	50.0%

Table 2. Event-level for Rethymno and Threshold shares for Rethymno

Metric	n (events)	Median(s)	IQR(s)
MinPET	18	5.65	0.81-7.91
minTTC	18	19.48	13.21-48.13
Threshold		**Count**	**% of events**
PET < 0.5 s		0/18	0.0%
PET < 1.0 s		5/18	27.8%
TTC < 3.0 s		0/18	0.0%
TTC < 5.0 s		0/18	0.0%

Rethymno presents larger safety margins overall (n=18). The minimum PET median is 5.65s (IQR 0.86-7.91), with 28.6%< 1.0s and 0%< 0.5s (Table 2). The minimum TTC median is 19.48s (IQR 13.21-48.13), and no events fall below 3.0s or 5.0s. Thus, while some events approach sub-second PET, very-high-risk PET (< 0.5s) is absent, and TTC never enters the < 5s at the critical instant, which is consistent with a less acute interaction profile than Athens.

Distributional tests (Table 3) show significantly lower minimum TTC in Athens, and the min TTC has a Mann-Whitney p = 0.043, while the minimum PET, based on the Mann-Whitney analysis, has a p = 0.093, demonstrating a strong trend. Athens shows far higher shares under TTC < 5s (50.0% vs 0.0%, p<0.001) and TTC < 3s (27.3% vs 0.0%, p=0.016). For PET, the very-high-risk band <0.5s is much more common in Athens (36.4% vs 0.0%, p=0.004), while PET < 1.0s remains higher in Athens but not statistically significant at $\alpha=0.05$ (50.0% vs 27.8%, p=0.154). Collectively, distributions and thresholds converge on the same result that illegal-crossing interactions in Athens are more acute and time-critical.

Table 3. Distributions based the Mann–Whitney U and Threshold contrasts (two-proportion tests)

Metric	Athens median (IQR)	Rethymno median (IQR)	p-value
min PET (s)	0.89 (0.21–1.20)	5.65 (0.86–7.91)	0.093
min TTC (s)	5.24 (4.36–13.24)	19.48 (13.21–48.13)	0.043
Threshold	**Athens**	**Rethymno**	**p-value**
PET < 0.5 s	8/22 (36.4%)	0/18 (0.0%)	0.004
PET < 1.0 s	11/22 (50.0%)	5/18 (27.8%)	0.154
TTC < 3.0 s	6/22 (27.3%)	0/18 (0.0%)	0.016
TTC < 5.0 s	11/22 (50.0%)	0/18 (0.0%)	<0.001

Taken together, the event-level minima and the updated threshold contrasts (Table 3) indicate a systematically higher severity of pedestrian-vehicle interactions in Athens relative to Rethymno. The TTC findings are both statistically robust and practically meaningful, with half of the Athens events breaching the 5-second band and none in

Rethymno. PET results point in the same direction, especially for the <0.5s band. While these conclusions are based on illegal-crossing events and finite minima (to avoid inflating with non-critical frames), they are consistent across metrics and tests, supporting targeted countermeasures in Athens and proportionate, context-sensitive measures in Rethymno.

4 Discussion

This study used event-level surrogate safety metrics, referring to the jaywalking events, to compare illegal crossings in two contrasting Greek urban contexts. By focusing on the critical frame of each illegal crossing (the minimum PET/TTC) and excluding infinite/no-contact frames, we targeted the moment of greatest risk rather than diluting severity with non-critical frames.

Findings are consistent and directionally clear, although they should be interpreted cautiously given the limited number of observed events and the site-specific nature of the analysis. More precisely, Athens exhibited more critical proximity than Rethymno, with lower medians for event-level minima and higher shares under stringent thresholds. The difference was statistically significant for minimum TTC (Mann–Whitney $p=0.043$), while minimum PET showed a strong trend ($p=0.093$). Threshold contrasts further reinforce the pattern of TTC < 5s occurring in 50% of Athens events versus 0% in Rethymno ($p=0.029$) and of PET < 0.5s being 37.5% vs 0% ($p=0.070$). These indicators align with the qualitative differences between sites, as Athens' dense arterial and long perceived signal delays near bus stops encourage opportunistic mid-block crossing under tighter vehicle approach conditions. Regarding the Rethymno location, despite tourist activity, it displayed larger safety margins on average.

5 Conclusions

Using low-cost smartphone video and an event-level surrogate safety approach, the quantification of the severity of illegal crossings at two contrasting Greek sites was implemented. By focusing on the minimum PET/TTC per event, across metrics and thresholds, Athens exhibited more acute pedestrian-vehicle proximity than Rethym-no, with a statistically significant separation in minimum TTC and a clear gap in the TTC<5s band, while PET differences aligned directionally but were weaker.

Policy implications differ by context. In Athens, signal timing optimization to reduce excessive pedestrian delay, and speed management (e.g., self-enforcing design, 30 km/h gateways) could reduce exposure and shorten crossing time. In Rethymno, where minima are generally higher, seasonal management and tourist-oriented way-finding and signage may be proportionate, with speed management during peak tourist periods to maintain generous TTC.

Some limitations of the study, such as the sample sizes and the ROI approach, which classified illegality without an explicit signal state, which is appropriate for non-designated areas, but does not capture all forms of non-compliance, should be examined at a later stage. Additionally, despite strong performance, the pipeline can incur false detections, ID switches, and missed tracks. Finally, a dedicated validation analysis for the present dataset was beyond the scope of this paper.

Future work should expand samples across time and locations, integrate exposure control (events per pedestrian-hour), and vehicle speed at conflict. Moreover, include mixed-effects regression (e.g., site-random effects) for PET/TTC minima and for threshold exceedance, and also conduct before-and-after assessments of low-cost countermeasures.

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