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EVALUATING PEDESTRIAN CROSSING ATTRIBUTES AT INTERSECTIONS IN KABUL CITY, AFGHANISTAN: A COMPUTER VISION APPROACH

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Abstract

This study aims to evaluate pedestrian crossing attributes in heterogeneous traffic environments using computer vision. For this purpose, YoloV8 models were optimised to detect pedestrian crossing attributes. Moreover, an OpenCV-based Python programme was developed to track pedestrian trajectories manually. For accuracy, the inverse perspective mapping method is applied to obtain a bird's eye view. Finally, a heatmap of pedestrian trajectories was provided to visualise the pedestrian crossing attributes. The results show that more than three-quarters of pedestrians are engaging in noncompliance crossing behaviours at major intersections in Kabul City, Afghanistan. In addition, pedestrians tend to walk longer, more frequent routes at corners and outside of crosswalks. Furthermore, statistical analysis reveals that pedestrian crossing speed decreased by 5.8% when disobeying crossing rules, indicating the significant effect of pedestrian attributes on crossing speed. In conclusion, this study contributes to a better understanding of pedestrian behaviour in heterogeneous traffic environments using computer vision. The results would provide insightful information to traffic engineers and planners for traffic management.

Keywords: Pedestrian Crossing Attributes, Computer Vision, Intersection, Heterogeneous Traffic Environment, Crossing Speed

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INTRODUCTION

The traffic environment becomes more complex when pedestrians violated the rules, particularly at intersections on urban arterial streets with heterogeneous traffic. Noncompliance crossing is a prevalent behaviour among pedestrians at intersections in developed countries. This phenomenon exposes pedestrians to consecutive conflicts and creates a high-risk environment for road users.

The heterogeneous traffic environment is defined as a traffic flow which is composed of different types of road users, including vehicles, bicycles, and pedestrians (Board et al., 2022). Heterogeneity of traffic flow is the main characteristic that differentiates traffic conditions in a developing country from those of a developed country (Pandey et al., 2022). It brings unique challenges to traffic management and safety in a developing country. Many studies have recognized that speed variation, longitudinal and lateral lane changing, distance keeping, traffic safety and other aspects of vehicular behaviour are more observable characteristics of heterogeneous traffic environments (Civil & Practice, 2020; Siregar et al., 2021; Ma et al., 2023). Furthermore, the traffic environment in Kabul City is characterised by a lack of lane discipline and weak traffic law enforcement, which causes pedestrians to resort to noncompliance crossing attributes.

Providing a safe and walkable environment for pedestrians is an important aspect of a vibrant urban environment. A lack of control over pedestrian crossing attributes results in a significant reduction in traffic operation efficiency. Pedestrian crossing attributes are affected by several factors such as waiting time on the curb side, traffic volume, walking speed, pedestrian distraction, pedestrian amenities, and nearby land use (Ghomi & Hussein, 2022). However, the impact of pedestrian noncompliance attributes on crossing speeds remains unclear in a heterogeneous traffic environment. Pedestrian crossing speed is a critical parameter to determine the efficiency of traffic operations and safety at intersections (Zafri et al., 2019). It is hypothesised that pedestrians' non-compliance crossing significantly reduce pedestrians crossing speed. On the other hand, computer vision has great potential for growth in evaluating pedestrian behaviour and safety in complex traffic environments. Its recent advances provide a promising outcome for evaluating pedestrian behaviour.

Therefore, understanding the effect of pedestrian crossing attributes on walking speed is one of important aspects of enhancing traffic operation and safety, particularly in complex traffic environment. Furthermore, research on pedestrian crossing attributes will be useful to enforce traffic regulations and control traffic operation (Kadali & Vedagiri, 2020). With this background, the current study aims to evaluate pedestrian crossing attributes in heterogeneous traffic environments using computer vision. To accomplish this, the following objectives should be achieved: (i) to determine the effectiveness of current advances of computer vison technique for evaluating pedestrian behaviour; (ii) to

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examine the effect of pedestrian attributes on their crossing speeds; (iii) to provide a framework to identify the location and density of pedestrian noncompliance behaviour in a heterogeneous traffic environment. The outcome will shed light on the pedestrian attributes in a complex traffic environment of a low-income city. It will provide insightful information to policy makers, traffic engineers, and planners to make evidence-based decisions.

LITERATURE REVIEW

Background of Pedestrian Crossing Behaviour Study

Walkability is an essential aspect of a transportation network for healthy and sustainable cities (Ghadzlie et al., 2024). Numerous studies have demonstrated that pedestrian crossing attribute is a crucial aspect of traffic management and explored it from various perspectives, including safety, health, and sustainable urban design (Karwand et al., 2023; Khalid et al., 2023; Read et al., 2018).

Previous studies identified that higher vehicular speeds, pedestrian and vehicle volumes, distraction, land use characteristics, and built environment factors are associated with increasing pedestrian collision rates (Hussain et al., 2019; Leh et al., 2013). A comparison of intersections and mid-block crash records shows that the collision rate is higher in the intersections located on urban arterial streets of non-residential areas than on residential roads (Quistberg et al., 2015). Most of these studies used recorded crash data to evaluate pedestrian safety. However, the availability of reliable historical crash data is limited for developing countries, particularly in low-income cities. Therefore, previous studies also attempt to conduct alternative approaches for evaluating pedestrian safety (de, Ceunynck, 2017). These alternative approaches are basically reliant to road users behavioural characteristics and built environment factors (Arun et al., 2021). A considerable number of studies have focused on evaluating pedestrians crossing behaviour in different types of traffic facilities using a variety of non-crash related approach. Thompson et al. (2013) conducted a field observation to determine pedestrian crossing time with distraction behaviour at intersections. They found that pedestrians take an additional amount of time to cross intersections compared to undistracted behaviour. Zafri et al. (2019) performed a screenshot taken from videographic methods to analyse pedestrian waiting time and crossing speed at three intersections in Dhaka City, Bangladesh. The results of their study show that pedestrians who do not want to wait more than 20-30 seconds to cross the road and pedestrian crossing speed bear reasons which are associated with intersection time, compliance behaviour, gender, age, and crossing location. A field observation of pedestrian illegal crossing was conducted by Shaaban et al. (2018) in mid-black of six lane streets of Doha City, Qatar. The results show that pedestrians used the shortest path to cross when crossing the streets without complying to rules. According to Goh et al. (2012), the types of crosswalks and gender significantly affect pedestrian crossing

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speeds. They carried out a manual time recoding in the City of Kuala Lumpur, Malaysia. According to Aceves-González et al. (2020) who conducted a physical audit and questionary survey in Mexico City, they highlight built environment factor and its effect on pedestrian safety perception. Pedestrian yield compliance depends on the speed of approaching vehicles and it varies in different locations and types of traffic facilities, which indicates the effect of environmental and demographic factor on pedestrian crossing behaviour (Chaudhari et al., 2021).

Most studies on pedestrian crossing behaviour tend to focus on certain types of traffic facilities and environmental context. However, almost all have not considered pedestrian noncompliance crossing at intersections on urban arterial streets, more specifically in the heterogeneous traffic environment of low-income cities. Although Kadali and Vedagiri (2020) have investigated the effect of various demographic and built environment factors on pedestrian crossing speed, less attention is still paid to the effect of pedestrian attributes on pedestrian crossing speeds. On the other hand, these studies conducted physical audits, field observations, manual time recording, and others which provided information on pedestrian behaviour at the beginning and end of their crossing trips. However, a robust and reliable understanding of pedestrian crossing attributes is required to obtain information on each time interval of the pedestrian crossing journey. This will be achievable using computer vision techniques.

Utilise Computer Vision Techniques

Computer vision refers to the technology that enables computers to extract meaningful information from visual data (Rosenfeld, 1988). Researchers have focused on its growing application in various domains, including transportation. In recent years, computer vision techniques have emerged as a promising method for evaluating pedestrian behaviour.

Several studies have utilized computer vision to study the movement characteristics of pedestrians (Ismail, 2010; Zangenehpour et al., 2015; Xia et al., 2022). They have focused on utilising two main aspects of computer vision: detection and tracking. Automated detection and tracking are challenging issues in the analysis of pedestrian movement patterns, particularly in heavy pedestrian traffic (Zaki & Sayed, 2013). In previous studies, image background subtraction, feature tracking, and optical flow techniques were found to be more commonly used for pedestrian detection and tracking (Fu, 2018; Hussein et al., 2015; Saunier et al., 2010). However, almost all these techniques inherit occlusion and error due to the constant change in the orientation and appearance of pedestrians. The field of computer vision is rapidly advancing and being developed day by day to overcome these challenges. For instance, there is You Only Look Once (YOLO) which is a deep learning-based object detection algorithm that can considerably overcome the challenges of occlusion due to its custom-trained feature. It can be trained to detect multiple objects in an image or video frame in real-time. YOLO was first introduced by Redmon et al. (2016) and has undergone several iterations. Its latest YOLOV8 version, developed by the Ultralytics team in 2023, has been highly improved in terms of accuracy and efficiency in object detection.

Among the reviewed literature, most studies have not utilized the YOLO model to evaluate pedestrian crossing attributes in a heterogeneous traffic environment. Furthermore, the challenges of full or partial occlusion were addressed in limited studies (Rezaei et al., 2022). To evaluate pedestrian crossing attributes in complex traffic environments, it is of great importance to accurately extract information on pedestrian crossing behaviour using computer vision. In this paper, researcher will discuss the potential of YOLOV8 model, to address the challenge of pedestrian crossing attributes at the intersections in Kabul City.

RESEARCH METHODOLOGY

The aim of this study is to evaluate the pedestrian crossing attributes in heterogeneous traffic environments using computer vision. To accomplish this, there are research material and method which consist of three main steps: (a) study site and data collection, (b) computer vision process, and (c) statistical analysis and data visualisation. The research design flow chart is shown in **Figure1**. It provides a framework for evaluating pedestrian behaviour in two visual views: perspective view and bird's eye view.

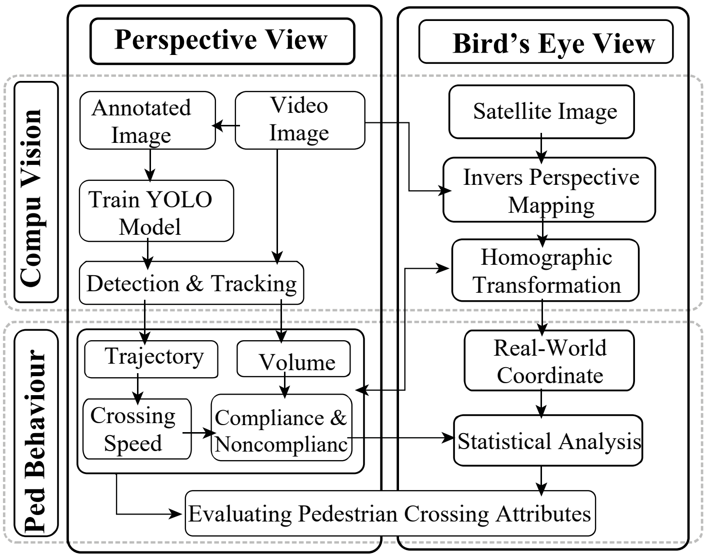

Figure 1: Research design flowchart

Study Site and Data Collection

The data collection process was conducted at the major intersections in the city of Kabul, Afghanistan. Intersections were selected based on traffic heterogeneity,

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location in the urban transportation network, and pedestrian activity criteria. Five major intersections were chosen as study sites, which are located on urban arterial streets (Baraki, Kart-e-Momureen, Deh Mazang, Chaman Hozori, and Chare Dan Bagh). Two types of data were collected: video data to evaluate pedestrian crossing attributes and images for annotation and training of the YOLO model.

Video data collection is prohibited at important intersections in Kabul City due to security concerns. Therefore, the research was only able to collect video data from the Baraki intersection. This intersection is in a strategic location that connects the north and south, as well as the east and west of the city. Data collection was carried out using a camera mounted on a building overlooking the intersection. The camera was set to record video with a resolution of 1280x720 pixels at 25 frames per second in MP4 format. The video data was collected for three days on June 13–15, 2021. A total of 26 hours of video footage was collected during these times. In total, 678 images were collected from five intersections with different views and angles. Images were annotated using LablImg, a Python-based image annotation software (**Table 1** and **Figure 3a**).

Table 1: Pedestrian image annotation dataset

Intersection	Images	Pedestrian Instances	Percentage
Baraki	225	6911	39.8%
Kart e Momureen	176	4096	23.6%
Deh Mazang	108	3912	22.5%
Chaman Hozori	72	1593	9.2%
Chare Dan Bagh	97	867	5.0%
Total	678	17378	100%

Computer Vision Process

Computer vision process is a crucial step that involves detecting and tracking pedestrians from a perspective and transforming their position into a bird’s eye view. A perspective view refers to the camera's viewpoint at ground level, and a bird's eye view provides a top view. The following techniques were used:

YOLOV8 Detection Model

YOLOV8 is the latest version of the YOLO series detection model. The YOLOV8 structure builds on the previous YOLO algorithm and has shown a great improvement in object detection performance (Jocher et al., 2023).

The YOLOV8 algorithm has a customised feature that allows it to be trained and optimised for a specific task. Considering this, the researcher trained three different models of YOLOV8 (YOLOV8n, YOLOV8s, and YOLOV8m) on the image annotation dataset collected from Kabul City intersections. Then, the performance of the models is compared based on common evaluation metrics: precision (P), recall (R), F1-score, average precision (AP), and mean average precision (mAP). Based on the outcomes, the optimal model is ultimately chosen.

Trajectory Extraction Technique

Evaluating pedestrian crossing attributes is a challenging task in an irregular traffic situation. It is required to accurately extract the entire crossing trajectory.

This study used video footage to extract the crossing trajectory. For this purpose, a Python manuscript is developed using the OpenCV library. It is designed to extract pixel coordinates and timestamps of pedestrian positions from video footage. Homographic transformation is applied to transform image pixels into real-world coordinates (cartesian coordinate system). The pedestrian trajectory extraction process is shown in **Figure 2**. It involves extracting pedestrian positions, homographic transformation, speed and its change estimation, and storing trajectories in a database for further analysis.

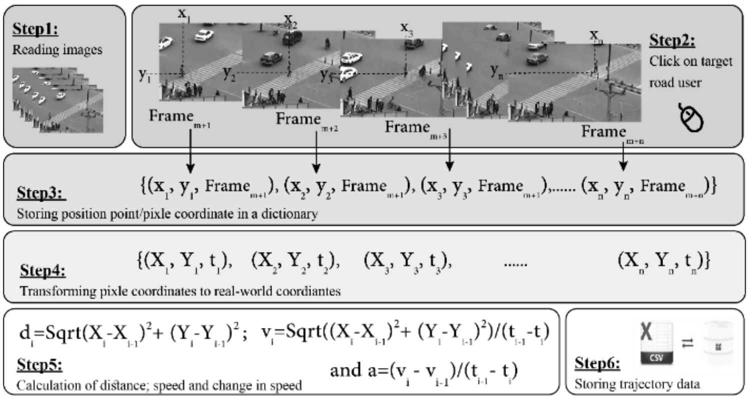

Figure 2: Pedestrian trajectory extraction process.

Perspective Transformation

Perspective view, such as object position in video footage, is not showing real position. It is associated with distortions and calibration is required. For calibration purposes, the researcher has applied IPM to align the perspective viewpoints on the satellite image of the same location. Then, transformation matrix is created to convert image pixel to cartesian coordinates system. The transformation can be carried out using the following equations:

$$X_c=\frac{g_{11}\times x+g_{12}\times y+g_{13}}{g_{31}\times x+g_{32}\times y+g_{33}} \quad \dots [1]$$

$$Y_c=\frac{g_{21}\times x+g_{22}\times y+g_{23}}{g_{31}\times x+g_{32}\times y+g_{33}} \quad \dots [2]$$

Where:

X_c, Y_c = cartesian coordinates system in meters [m]
x, y = image pixel coordinates
g_{ij} = transformation matrix values

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Statistical Analysis and Data Visualisation

The computer vision technique is used to obtain pedestrian volume, crossing speed, compliance and noncompliance crossing attributes, and pedestrian density or the number of pedestrians occupying a certain area. The obtained data were analysed in two forms: statistical analysis and pattern visualisation.

First, descriptive analyses were carried out. In addition, comparative statistical analysis, which uses ANOVA and student t-tests, was conducted to determine the effect of pedestrian attributes on crossing speeds. Then, the kernel density estimate (KDE) was applied to pedestrian crossing trajectory data to visualize the pattern of pedestrian crossing attributes at intersections.

RESULTS AND DISCUSSION

The results of this study are discussed from two perspectives: computer vision effectiveness in data acquisition of pedestrian crossing attributes and evaluation of pedestrian crossing attributes. The results show that computer vision techniques are extremely effective in pedestrian crossing attributes detection and analyses of their whole crossing trajectories. Through data analysis, it was observed that noncompliance crossing is a prevalent behaviour among pedestrians at the intersections studied.

Results of Using Computer Vision

Results from computer vision process are presented with regard to the three sections included in the research methodology: YOLOV8 detection model, pedestrian trajectory extraction, and perspective transformation.

Optimising YOLOV8 Detection Model

The results of YOLOV8 detection model involves creating pedestrian image annotations dataset, training three different YOLOV8 models (YOLOV8n, YOLOV8s, and YOLOV8m), and test the performance of trained models.

To begin with, overall, 17378 instances of pedestrians were annotated on 678 images collected from five intersections. The result of the pedestrian annotation is provided in **Table 1**. LabelImg software was used to manually annotate images, as shown in **Figure 3a**. Then, YOLOV8 models were trained in Google Colab with a GPU accelerator using a Roboflow notebook. For each model, 640×640 image size, 150 epochs, and a 0.001 learning rate were arranged in 16 batch runs. The performance results of the models are shown in **Table 2**. The performance of three models was also tested on the same images (**Figure 3**). All three models show acceptable inference speeds. The results indicated that YOLOV8n has a faster inference speed (1.4 milliseconds) with a lower successful detection rate (3 wrong deductions and 8 missed deductions, as shown in **Figure 3d**). In conclusion, YOLV8m was found to be an optimal model with an acceptable inference speed (9.8 milliseconds) and a higher mAP50-95%.

Table 2: Performance evaluation of YOLOV8 models

Model	R%	P%	mAP50%	mAP50-95%	F1-score	Inference
YOLOV8n	0.922	0.921	0.926	0.706	0.921	1.4 m.sec
YOLOV8s	0.959	0.953	0.955	0.813	0.956	3.7 m.sec
YOLOV8m	0.970	0.968	0.969	0.761	0.968	9.9 m.sec

(**a**): 46 pedestrians annotated on image
(**b**): 1 missed detection
(**c**): 5 missed and 1 wrong detection
(**d**): 8 missed and 3 wrong detections

Figure 3: Models test (green box, red box, and bule box are shown successful, missed, and wrong detection respectively). (**a**) annotated image using LabelImg software, (**b**) YOLOV8m, (**c**) YOLOV8s, and (**d**) YOLV8n.

Results of Pedestrian Trajectory Extraction

The trajectory extraction technique was used to obtain pedestrian crossing trajectories for interested regions of crosswalks. A total of 1264 crossing trajectories were extracted, and almost 23% of the pedestrians is obeyed traffic rules. **Figure 4** shows the two-hour pedestrian crossing trajectories of the 9:15 to 11:15 a.m. segment of video data on June 15, 2021.

Transforming Pedestrian Trajectory to Bird's Eye View

The results of pedestrian crossing trajectories that transformed to a bird's eye view, namely the ground plane, are shown in **Figure 5b**. Results of the trajectory data, originally from video footage pixels, are unreliable. To address this issue, the inverse perspective mapping was applied to overlay the corresponding point of video footage and satellite image of the same location (**Figure 5a**). A transformation matrix was found between two planes using OpenCV library.

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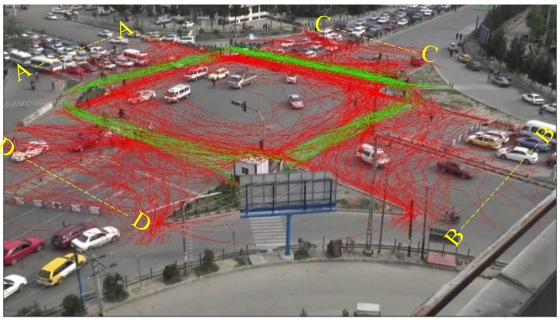
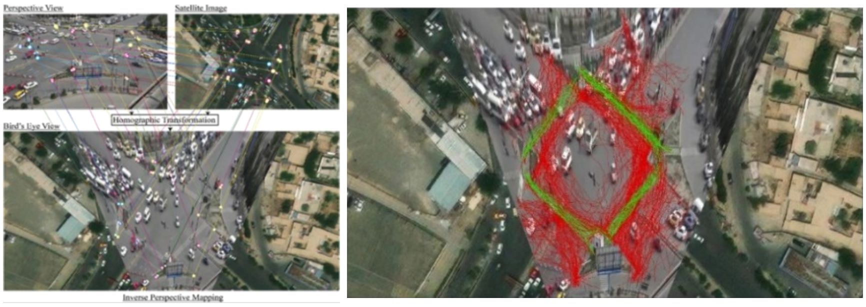


Figure 4: Pedestrian crossing trajectories (red and green shows noncompliance and compliance crossings respectively)



(**a**) (**b**)

Figure 5: Inverse perspective mapping. (**a**) Overlaying video footage on satellite image, (**b**) Transforming pedestrian trajectories to bird's eye view

Evaluation of Pedestrian Crossing Attributes

A statistical analysis and data visualisation method were used to evaluate pedestrian crossings by pedestrian volume count, compliance and noncompliance pedestrian crossings, pedestrian crossing speeds, and pedestrian density. A summary of the data description is presented in **Table 3**.

First, the YOLOV8m detection model was used to automatically count pedestrian crossings in every 50 frames (2 sec). The results of the pedestrian volume count during 12,000 frames for four crosswalks are shown in **Figure 6**. Additionally, the hourly pedestrian crossing on each crosswalk, with compliance and noncompliance attributes, is provided in **Table 3**. The results show that overall, 717 pedestrians per hour cross the Baraki intersection. The crosswalk C-C, with 221 pedestrians per hour, is the most crowded spot among others. It was observed that almost 87% of the pedestrians crossed in a noncompliance manner. Furthermore, based on the KDE, the pedestrian crossing density was visualised using video footage and a satellite image. As shown in **Figure 7b**, it is obvious that pedestrians created several prohibited routes in the vicinity and corners of each crosswalk, indicating a negative impact on traffic operations. However, major intersections on urban arterial streets must provide higher traffic mobility.

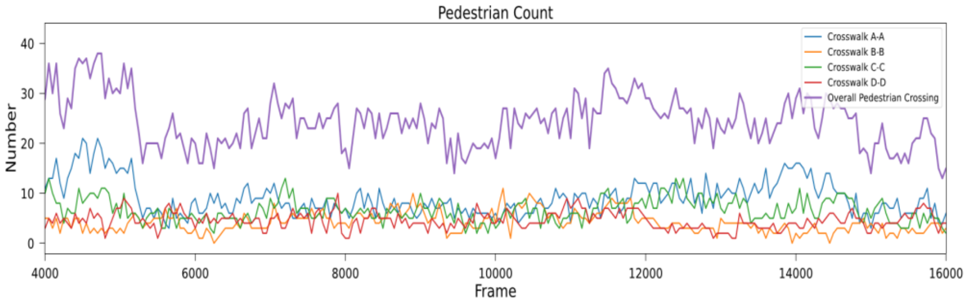
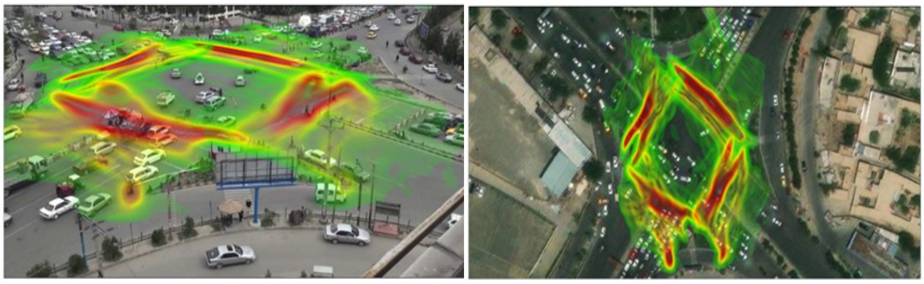


Figure 6: Pedestrian volume count



(**a**) (**b**)

Figure 7: Pedestrian crossing density visualisation. (**a**) perspective view, (**b**) bird's eye view –satellite image

From the results, it was found that the mean pedestrian crossing speed was 1.282 m/s for noncompliance and 1.212 m/s for compliance manner, respectively. For comparison purposes, the distribution and variation of crossing speed data are visualised in **Figure 8**. The data are approximately normally distributed; the outer quartile and whisker lengths are symmetrical. However, noncompliance data have shown a wider range of variability than compliance, indicating the stopping and going of pedestrians. As shown in **Table 3**, statistical analysis reveals that pedestrian crossing speeds with noncompliance are significantly faster than compliance (equal variances assumed: $t\,(14864) = 5.966$, $p < 0.001$). This difference is also consistent and significant at all crosswalks.

Welch ANOVA was performed to determine the effect of factors on pedestrian crossing speeds. In addition, the pedestrian crossing attribute's effect on pedestrian crossing speed was explored. The results showed that pedestrian crossing speed was significantly affected by pedestrian attributes ($F\,(1, 14858) = 35.594$, $p<0.001$; Welch: $F\,(1, 2663.857) = 41.045$, $p < 0.001$). In addition to that,

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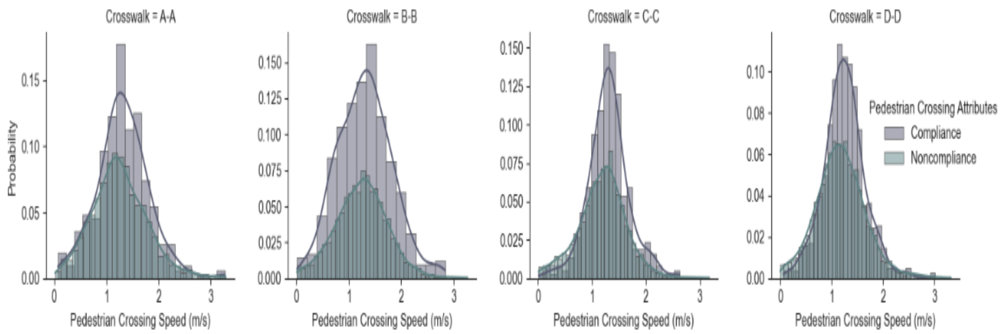
the ANOVA results revealed a significant effect of crosswalks on pedestrian crossing speed (F (3, 14862) = 19.960, p <0.001; Welch: F (3, 6723.137) = 19.027, p <0.001). In summary, analysis indicated that pedestrian attributes and crosswalks have a significant impact on pedestrian crossing speed. However, other factors also need to be explored.

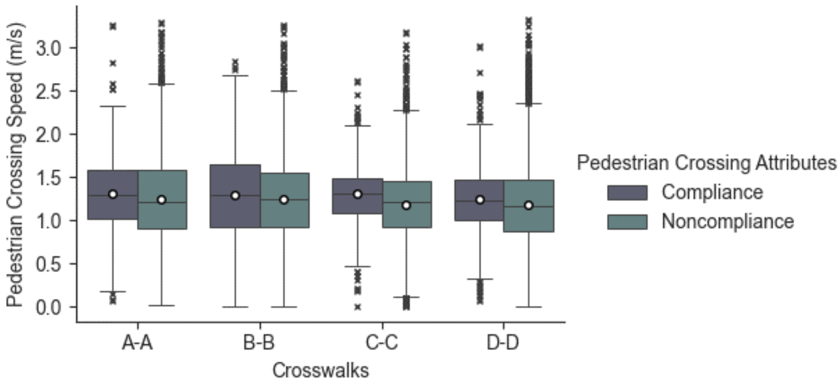
Table 3: Summary of pedestrian crossing attributes

Crosswalks	**Crossing Attributes**	**PCPH**[1] **(`percentage)**	**Pedestrian Crossing Speed (m/s)**			
			Sample Size (*N*)	**Mean** (μ)	**Std. Deviation** (S)	**Sig.** (p-value)
A-A	Noncompliance	87(0.12)	1755	1.255	0.5244	0.0469[a]
	Compliance	16(0.02)	310	1.319	0.4993	
B-B	Noncompliance	183(0.26)	3647	1.247	0.4956	0.0312[a]
	Compliance	24(0.03)	418	1.302	0.5141	
C-C	Noncompliance	188(0.26)	3183	1.1921	0.4503	0.0000[a]
	Compliance	33(0.05)	374	1.3064	0.3801	
D-D	Noncompliance	166(0.23)	4358	1.180	0.483	0.0002[a]
	Compliance	20(0.03)	821	1.247	0.3998	
Overall	Noncompliance	624(0.87)	12943	1.212	0.4857	0.0000[a]
	Compliance	93(0.13)	1923	1.282	0.4411	

[1] Pedestrian crossing per hour
[a] p-value < 0.05 was considered statistically significant.



(a)



(**b**)

Figure 8: Pedestrian crossing speed distribution. (**a**) Normal distribution, (**b**) measure of variation (boxplot visualisation)

CONCLUSION

This study attempted to address the issue of pedestrian crossing attributes in the heterogeneous traffic environment of a low-income city. To accomplish this, the advantages of recent advances in computer vision techniques were successfully utilised with the help of the Python-based OpenCV library.

Computer vision techniques have been found to be extremely effective in extracting pedestrian crossing-related information. It provides a trajectory-based analysis of pedestrian crossing attributes, resulting in an instantaneous analysis of pedestrian behaviour. In addition, it has proven to be highly useful to analyse pedestrian movement characteristics in multiple planes, which allows for the analyse of the exact positions of movement objects.

The results show that noncompliance crossing is a prevalent behaviour at major intersections in Kabul City. Trajectory data revealed that pedestrians tend to create prohibited routes at corners and outside of crosswalks, indicating higher traffic irregularities. In contrast to Shaaban et al. (2018), pedestrians take a longer path when they do not obey crossing rules. Pedestrians have substantially lower crossing speeds when crossing in a noncompliance manner. In fact, Zafri et al. (2019) found a similar result. Furthermore, results from the ANOVA show that pedestrian crossing speed is significantly affected by pedestrian attributes and crosswalks. However, other factors need to be further investigated. In conclusion, this study provides valuable information to better understand the challenges of urban traffic management and planning in heterogeneous traffic environments.

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