Evaluating roundabouts safety performance based on vehicle trajectory analysis through UAVs

Fotini Kehagia, Apostolos Anagnostopoulos*

Highway Laboratory, Dept. of Civil Engineering, Aristotle University of Thessaloniki, 54124, Greece

** Corresponding author: fkehagia@civil.auth.gr / https://gr.linkedin.com/in/fotini-kehagia-01328b40*

Abstract

As the number of modern roundabout installations continues to increase in Greece, there is a need for a detailed study of their safety performance. The main purpose of this study is to examine innovative tools and approaches to evaluate roundabouts safety performance. A traffic conflict analysis was carried out to diagnose unsafe conditions at two recently installed multilane roundabouts. A lightweight quadcopter UAV was used to record roundabouts performance. Vehicle trajectories were extracted, and surrogate safety indicators were applied. The severity and the location of traffic conflict events were identified and further examined to assess the need for the potential application of effective road safety interventions. Analysis and results revealed that the severity of conflicts is associated with the geometry of the roundabout and the traffic flow as well.

Keywords

Road safety; traffic conflict; UAV; Surrogate safety measure; PET.

Introduction

Traffic safety is an area of transportation engineering characterized by increased attention and awareness. Traffic fatalities are one of the leading causes of death around the world. The European Union (EU) has the ambition to reduce the number of road deaths and the number of serious injuries by 50% between 2020 and 2030 (European Commission, 2018). Upon this, to achieve the long-term goal of moving close to zero fatalities in road transport by 2050, it is necessary for effective actions to be adopted.

Roundabouts became an increasingly appealing alternative form of at-grade intersections because of their effectiveness primarily in traffic safety (Rodegerdts, et al., 2010). Based on that, roundabouts have gained increased political acceptance worldwide during the last decades and nowadays are considered a reasonable alternative for intersection design.

Their implementation on a road network is an efficient solution in cases of traffic safety issues and low-capacity conditions. Roundabouts are statistically safer for motorists than other at-grade intersections because of lower vehicle speeds, reduced crash angles and fewer conflict points. Several before-and-after studies of roundabout conversions indicate that modern roundabouts are safer than previous intersection treatments (Schoon and Van Minnen, 1994; Silva, et al., 2014). However, the most important reason of this widespread design solution, is the effectiveness in reducing the number of road fatalities (Rodegerdts, et al., 2007).

For many years, the traffic safety assessment of new traffic treatments was a difficult task because of the lack of good predictive models of crash potential (Gettman and Head, 2003). During the last decades, most studies have relied on analysing historical data to evaluate road traffic safety. However, the collection of accident statistics can be a time-consuming process, and in many cases, data are missing.

As the number of modern roundabout installations continues to increase in Greece, there is a need for a detailed study of their safety performance. Surrogate safety measures (SSMs) can be considered an efficient approach to examining potential safety issues, as the lack of historical roundabouts accident data is a fundamental limitation in Greece. Surrogate safety measures are used to quantify the crash probability and/or the potential crash severity between two road users in a traffic event.

In the "EU road safety policy framework 2021-2030" package, the European Commission (2019) put forward a new approach to EU road safety policy. As regards infrastructure safety, the Commission highlights the need for further research and innovation on infrastructure safety by using the new technology for monitoring infrastructure conditions. Upon this, the forthcoming gradual changes in vehicle characteristics and the road environment (e.g., the foreseen coexistence of conventional and automated vehicles on the same network) require new safety performance criteria and applications of innovative surrogate safety analysis techniques (Anagnostopoulos and Kehagia, 2020).

Unmanned aerial vehicles (UAVs), commonly known as drones, are recently being used in transportation field to monitor and analyze the traffic flow. The collection and analysis of high-resolution data such as vehicles trajectories are challenging concerning the analysis of driving behaviour (Kehagia, et al., 2022).

According to the existing literature, many studies have been conducted dealing with safety analysis performance using video processing techniques for detecting and analyzing traffic events (Laureshyn & Ardo, 2006; St-Aubin et al., 2015). The effort of UAVs in this process is promising and a limited number of studies address the potential efficiency of this approach.

The benefits of deploying UAVs for traffic monitoring and analysis have been considered in several studies (Anagnostopoulos and Kehagia, 2021; Khan, et al., 2017; Kanistras, et al., 2015; Salvo, et al., 2017). UAVs provide a wide field of view, which is efficient for monitoring multiple entries of roundabouts. Moreover, the drivers' attitude is not distracted by the equipment and the extracted data represent naturalistic driving behaviour. However, there are many factors that negatively affect the performance of this process. Weather conditions (e.g., rain and strong winds), technical issues (e.g., low battery duration), regulatory issues (e.g., no-fly zones), and safety issues (e.g., the existence of power lines in the study area) can significantly affect the process of traffic surveys.

The main purpose of this study is to examine innovative tools and approaches to evaluate roundabouts safety performance. A traffic conflict analysis was carried out to diagnose unsafe conditions at two recently installed multilane roundabouts. The severity and the location of traffic conflict events were identified and further examined to assess the need for the potential application of effective road safety interventions (e.g., pavement marking).

Methodology

A specific methodology was applied to ensure the proper selection of roundabouts for the analysis. The selection process was based on roundabouts' geometric elements, traffic volumes, and location characteristics. Finally, on-field data were collected from two modern multilane roundabouts constructed recently in Thessaloniki (Greece). Field measurements were conducted during peak periods to ensure saturated traffic conditions and greater possibilities to capture traffic conflict events.

For the specific experiment, a lightweight quadcopter UAV was used. The selected UAV captured videos up to C4K analysis with a frame rate of 60 fps and high-resolution images (5472x3078). Its camera is attached to a gimbal, which stabilize shots. The specific setup has a maximum flight time of

20 minutes in ideal weather conditions and can be expanded by new batteries if necessary. Finally, 100 minutes were filmed for each roundabout. Figure 1 presents UAV shots of the examined roundabouts.

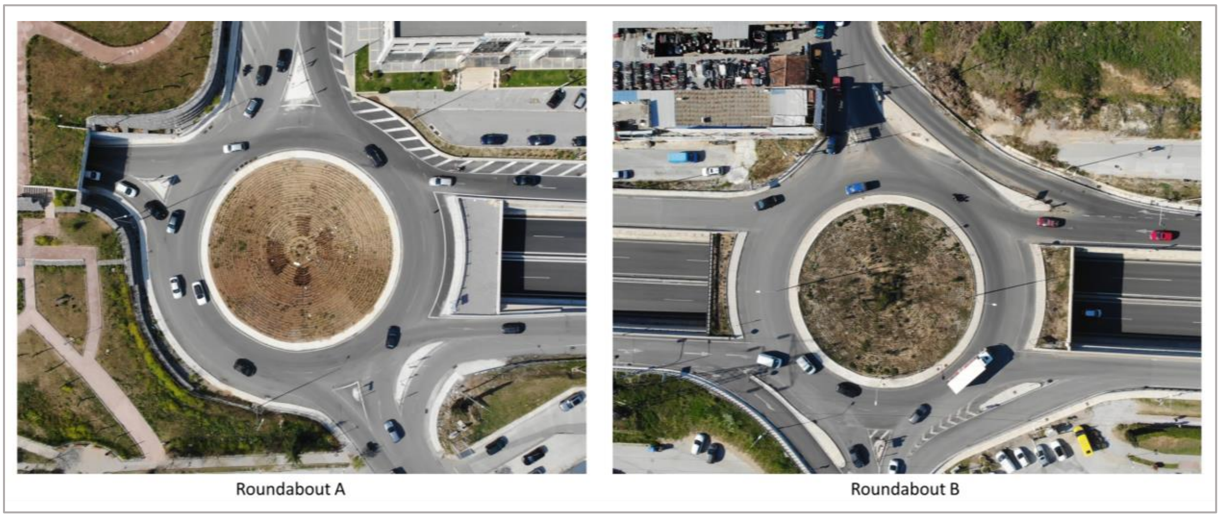

Figure 1: UAV shots of the examined roundabouts.

The methodology followed for the evaluation of roundabouts safety performance is briefly described below and presented in Figure 2. Specific lengths on the ground were measured with high accuracy using measuring tape during the field surveys and allowed the extraction of reliable geometric elements of the examined roundabouts using appropriate CAD software.

Following, specific events of traffic interactions and potential traffic conflicts were identified and selected for further analysis. More specifically, all interactions that seemed dangerous were manually preselected by the observer. Next, Tracker software was used to accurately measure the severity of the situation and to decide whether it was a serious traffic conflict or not. A semiautomatic process technique was performed on the identified video image sequences by adopting a Cartesian coordinate system and extracting vehicle’s trajectories. The extracted trajectories confirmed where necessary the existence of traffic conflicts which were further analysed for the calculation of surrogate safety indicators.

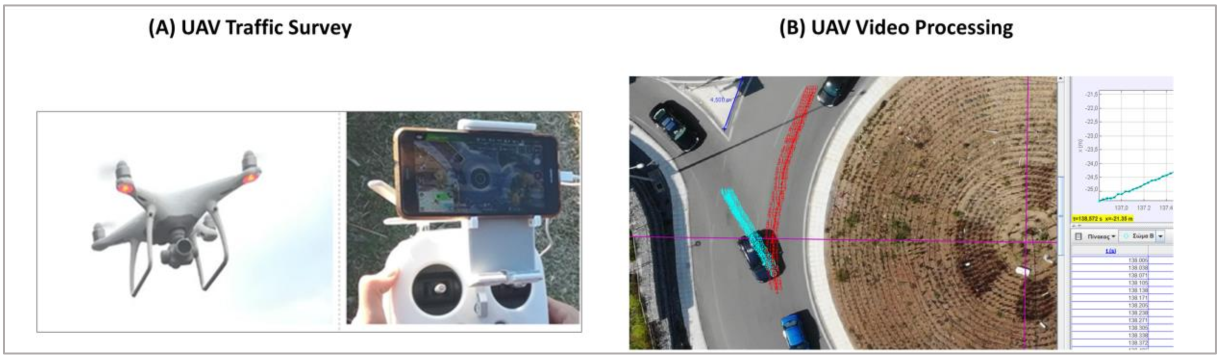

Figure 2: The general process for performing the safety analysis.

Analysis and Results

Dozens of surrogate safety indicators have been developed over the decades (Laureshyn & Ardo, 2006). In the present study, Post-Encroachment Time (PET) was used as the proximal indicator to assess the safety of the roundabouts. PET is defined as the time between the first road user leaving a conflict area and the second one arriving at it (Allen et al., 1978). A lower PET value indicates a higher probability of collision.

Several studies have shown that a threshold value of PET between one and two seconds represents an interaction and a risk of collision between road users (Pessapati et al., 2013; Keshuang and Kuwahra, 2011). Therefore, the threshold of 2 sec was used in this study and PETs larger than two seconds were removed from the analysis. Moreover, PETs were classified into three time-intervals based on their risk of collision. PETs less than 1 second represent a high risk, PETs among values of 1 and 1.5 seconds represented a moderate risk and finally, PETs among values of 1.5 and 2 seconds represented a low risk.

Results of the analysis, for each entry leg of the roundabouts, are presented in the following Figure.

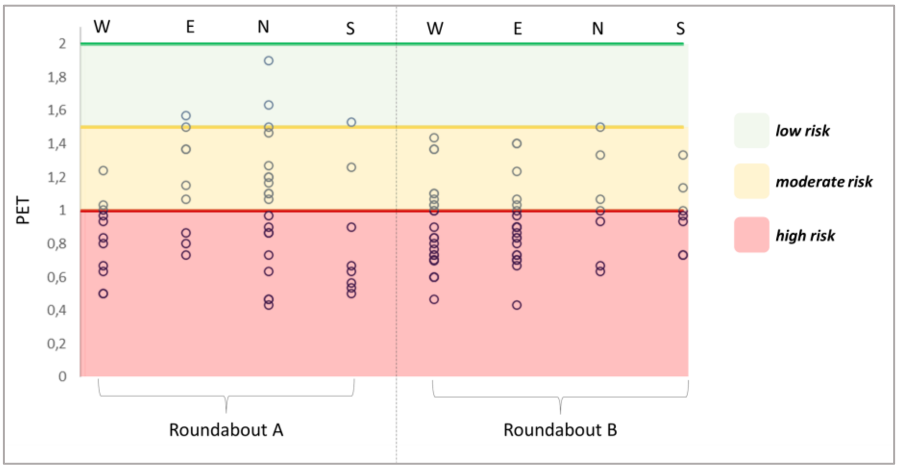

Figure 3: UAV shots of the examined roundabouts.

A more detailed approach of the analysis is presented in Figure 4. More specifically, a heatmap of the spatial distribution of the observed traffic conflicts provides a visual inspection of the safety issues for Roundabout A. This method encourages the adoption of local interventions (e.g., pavement marking) for future improvements of the intersections.

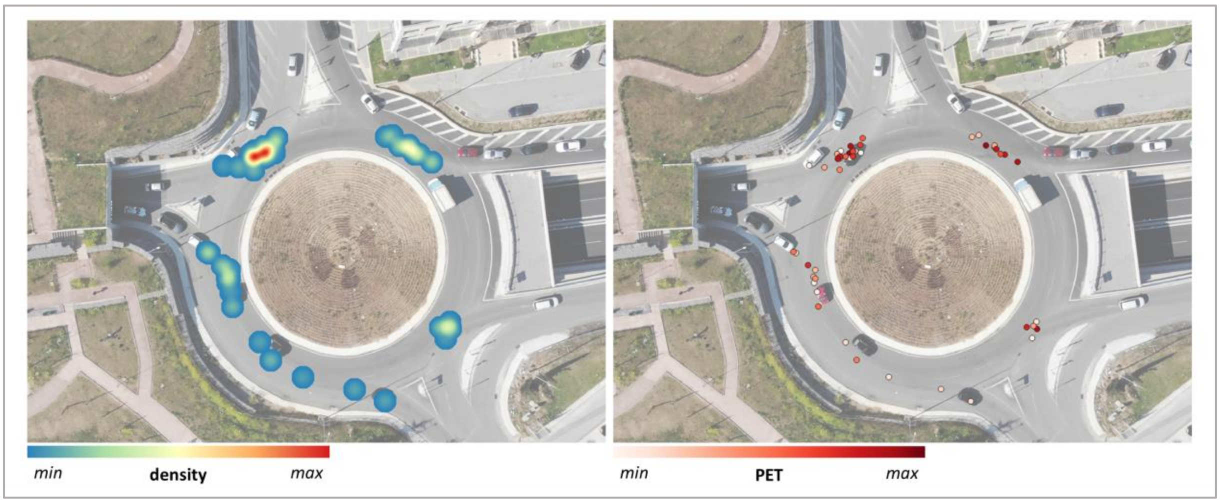

Figure 4: The heatmap of the observed traffic conflicts (left) and the location of the traffic conflicts considering severity (right).

A total number of 48 and 61 PETs have occurred in Roundabout A and Roundabout B respectively. According to the Figure, it is observed that the most common traffic conflicts observed are conflicts between entering vehicles and circulating vehicles (41 lateral collisions), while fewer conflicts between circulating vehicles were occurred (7 rear-end collisions). Moreover, the safety analysis presented graphically, highlights that the geometric design of the north entrance should be further examined.

Finally, to determine the relationship between improper driving behaviour (average value of observed PETs on entry roundabout legs) and the roundabouts geometric features or the vehicular traffic, a correlation analysis was carried out. The Pearson correlation analysis was applied to examine the correlation between the variables.

Table 1: Correlation analysis.

Variables	Correlation Coefficient
Entry width	-0.352**
Entry radius	0.645**
Entry angle	-0.530**
Inscribed circle diameter	0.322**
Central island diameter	0.322**
Splitter island width	0.431**
Splitter island length	0.763**
Entry flow	0.689**
Circulating flow	-0.434**

values along with "**" are significant at 0.01 level and values along with "*" are significant at 0.05 level.

The highest significant positive correlation is identified between PET and splitter island width ($r = 0.763$, $p < 0.001$). According to this, it is concluded that the length of splitter islands can affect efficiently the safety of roundabouts. On the other hand, it is observed that as the entry angle gets higher, the severity of the conflict increases ($r = -0.530$, $p < 0.001$). Moreover, it is indicated that roundabout approaches characterized by high circulating traffic volumes should be further examined with respect to traffic safety.

According to the correlation analysis results, it is revealed that the severity of conflicts is associated with the geometry of the roundabout and the traffic flow as well. Nevertheless, it is noted that the sample of the examined roundabout entries is limited (8 cases).

Conclusions and Discussion

The design of the geometry of a roundabout involves choosing between trade-offs of safety and capacity. The appropriate selection of the geometric parameters for the design of the roundabout can enhance operational performance and traffic safety.

The main purpose of this study is to examine innovative tools and approaches to evaluate roundabouts safety performance. A traffic conflict analysis was carried out to diagnose unsafe conditions at two recently installed multilane roundabouts. Roundabouts' performance was recorded with the use of a quadcopter UAV.

In the present study, Post-Encroachment Time (PET) was used as the proximal indicator to assess the safety of the roundabouts. The severity and the location of traffic conflict events were identified and further examined to assess the need for the potential application of effective road safety interventions.

According to the developed heatmaps of the spatial distribution of the observed traffic conflicts, a visual inspection of the safety issues for roundabouts is proposed. This method encourages the adoption of local interventions for future improvements of the intersections.

Results of the conflict analysis highlighted that the most common traffic conflicts of roundabouts are conflicts between entering vehicles and circulating vehicles (lateral collisions), while conflicts between circulating vehicles (rear-end collisions) can occur as well.

According to the correlation analysis results, it is revealed that the severity of conflicts is associated with the geometric features of the geometry of the roundabout and parameters of the traffic flow as well. The highest significant positive correlation was identified between PET and splitter island width. Finally, the analysis highlighted that the severity of the conflict increases as the entry angle gets higher. Nevertheless, it is noted that the sample of the examined roundabout entries is limited (8 cases). More case study roundabouts of various geometric features should be further analysed to validate the results of this study and develop a reliable tool for road safety assessment.

References

Allen, B. L., Shin, B. T., & Cooper, P. J. (1978). Analysis of traffic conflicts and collisions. *Transportation Research Record ,667*, pp. 67-74.

Anagnostopoulos, A., & Kehagia, F. (2021). Utilizing UAVs Technology on Microscopic Traffic Naturalistic Data Acquirement. *Infrastructures, 6*(6), 89. https://doi.org/10.3390/infrastructures6060089

Anagnostopoulos, A., & Kehagia, F. (2020). CAVs and Roundabouts: Research on traffic impacts and design elements. *Transportation Research Procedia, Volume 49*, 83–94. https://doi.org/10.1016/j.trpro.2020.09.008

European Commission (2019). *EU Road Safety Policy Framework 2021-2030: next steps towards 'Vision Zero'*. European Commission: Brussels, Belgium, 2019.

European Commission (2018). *Europe on the Move - Sustainable Mobility for Europe: safe, connected, and clean* - COM/2018/293 Final. European Commission: Brussels, Belgium, 2018.

Gettman, D.M., & Head, L. (2003). Surrogate Safety Measures from Traffic Simulation Models. *Transportation Research Record, 1840*, 104 - 115. https://doi.org/10.3141/1840-12

Kanistras, K., Martins, G., Rutherford, M.J., & Valavanis, K.P. (2015). Survey of Unmanned Aerial Vehicles (UAVs) for Traffic Monitoring. In: Valavanis, K., Vachtsevanos, G. (eds) *Handbook of Unmanned Aerial Vehicles*. Springer, Dordrecht. https://doi.org/10.1007/978-90-481-9707-1_122

Kehagia, F., Anagnostopoulos, A., Damaskou, E., & Mouratidis, A. (2022). An analysis on impact of geometric elements of multilane roundabouts on driver behavior, 6th International Symposium on Highway Geometric Design (ISHGD), Amsterdam, Netherlands.

Khan, M., Ectors, W. T., Bellemans, D., Jassens, D., & Wets, G. (2017). UAV-Based Traffic Analysis: A Universal Guiding Framework Based on Literature Survey. Transportation Research Procedia, Volume 22, 541–550. https://doi.org/10.1016/j.trpro.2017.03.043

Laureshyn, A., & Ardo, H. (2006). Automated video analysis as a tool for analysing road user behaviour. In R. Risser (Ed.), *Proceedings of ITS World Congress*, London.

Peesapati, L. N., Michael P. H., & Rodgers, M. O. (2013). Evaluation of Post-encroachment Time as Surrogate for Opposing Left-Turn Crashes. The 92nd Annual Meeting of TRB, No. 0839, Washington, D.C.

Keshuang, T., & Kuwahara, M. (2011). Implementing the Concept of Critical Post Encroachment Time for All-Red Clearance Interval Design at Signalized Intersections. *Journal of the Eastern Asia Society for Transportation Studies, 9 (0)*, pp. 1485-1498.

Rodegerdts, L., J. Bansen, C. Tiesler, J. Knudsen, E. Myers, M. Johnson, M. Moule, B.Persaud, C. Lyon, S. Hallmark, H. Isebrands, R. B. Crown, B. Guichet & A. O'Brien. (2010). *NCHRP Report 672*

Roundabouts: An Informational Guide (2nd ed.).Transportation Research Board of the National Academies, Washington, D.C.

Rodegerdts, L., M. Blogg, E. Wemple, E. Meyers, M. Kyte, M. Dixon, G. List, A.Flannery, R. Troutbeck, W. Brilon, N. Wu, B. Persaud, C. Lyon, D. Harkey & D. Carter. (2007). *NCHRP Report 572: Roundabouts in the United States*. Transportation ResearchBoard of the National Academies, Washington, D.C

Salvo, G., Caruso, L., Scordo, A., Guido, G., Vitale, A. (2017). Traffic data acquirement by unmanned aerial vehicle. *European Journal of Remote Sensing, 50:1*, 343-351. https://doi.org/10.1080/22797254.2017.1328978

Schoon, C. C., & J. van Minnen. (1994). The Safety of Roundabouts in the Netherlands.*Traffic Engineering & Control, Vol. 35, No. 3*, pp. 142-148.

Silva, A. B., L. Vasconelos, & S. Santos. (2014). Moving from Conventional Roundabouts to Turbo-Roundabouts. *Procedia - Social and Behavioral Sciences, 111*, 137-146.

St-Aubin, P., Saunier, N., & Miranda-Moreno, L. (2015). Large-scale automated proactive road safety analysis using video data. *Transportation Research Part C: Emerging Technologies , vol. 58*, no. B, pp. 363–379. https://doi.org/10.1016/j.trc.2015.04.007