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TIME-TO-COLLISION ANALYSIS AT MODERN ROUNDABOUTS

Pelin Onelcin, Yalcin Alver
Ege University, Department of Engineering, Civil Engineering Department, Türkiye

Abstract

Roundabouts have been shown to reduce fatalities and injuries at intersections. However, there is still room for improvement and a better understanding of their safety performance is needed, especially considering the anticipated increase in roundabout construction in the future. This study aims to determine the critical Time to Collision (TTC) value for conflicts between entering and circulating vehicles at modern roundabouts. Three modern roundabouts in Izmir, Türkiye, were chosen for data collection. Video data was collected using Unmanned Aerial Vehicles (UAVs) and processed using the AIMSUN simulation program to obtain vehicle trajectories. The Surrogate Safety Assessment Model (SSAM) was then used to determine the critical TTC value for each roundabout. The calibrated TTC values for the three roundabouts were found to be 1.58 s, 3.00 s, and 4.9 s. These differences are believed to be due to variations in traffic volume, composition, and geometry. The results of this study suggest that there is no single critical TTC for conflicts between entering and circulating vehicles at modern roundabouts. Instead, it is important to consider the specific characteristics of each roundabout, such as traffic volume, composition, and geometry. This study also implies directions for future research and practical applications, suggesting the need for pilot studies across various intersection types to validate its findings.

Keywords: modern roundabouts, time-to-collision, conflict analysis

1 Introduction

The increasing global population has significantly contributed to the increasing transportation demands in urban areas. The increased volume of vehicles on the roads has also given rise to safety concerns. The higher the number of vehicles, the greater the potential for accidents and collisions. Addressing the safety issues requires in-depth research and dedicated efforts.

Due to factors such as the infrequent nature of accidents, the need for longer observation periods, and incomplete information in the reports, alternative methods have replaced traditional approaches using accident reports [1, 2]. Since every accident occurs as a result of a conflict, the use of conflict data in safety analysis has been widely accepted.. The concept of traffic conflict was initially proposed by [3]. They defined traffic conflicts as instances of evasive actions, such as vehicle braking or weaving, as evidenced by brake light indication or lane change. The use of traffic conflicts in safety analysis has led to the emergence of various traffic measures. All these measures can be evaluated under the name of Surrogate Safety Measures (SSMs). The most commonly used measure is the Time-to-Collision (TTC), which represents the remaining time before two vehicles collide if no evasive action is taken by the driver [4].

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Compared to other traffic control types, roundabouts offer greater safety and operational benefits [5]. Sadeq and Sayed (2016) conducted a study on conflicts at a modern roundabout in Vancouver, utilizing the TTC measure for conflict analysis. Automatic identification of traffic conflicts allowed for a thorough analysis of road user behaviors and facilitated understanding of the underlying causes of traffic conflicts. The study aimed to improve understanding of traffic behaviors and the underlying reasons for conflicts, thus contributing to enhanced road safety [6]. Gallell et al. (2017) investigated conflicts at a roundabout in Italy. Unmanned aerial vehicles were employed to capture images and determine TTC values by plotting vehicle trajectories as they approached the roundabout. The distribution of rear-end collision conflicts and corresponding TTC values were obtained using the Surrogate Safety Assessment Program (SSAM) [7].

Ozbay et al. (2008) stated that one of the most used microsimulation programs in studies was AIMSUN [8]. The most commonly used approach to identify surrogate safety measures is to employ a post-processor on the output data obtained from a simulation model. The Federal Highway Administration (FHWA) developed the Surrogate Safety Assessment Model (SSAM) for this purpose [9]. The SSAM model processes trajectories produced during the simulation, including the vehicle's position, speed, and acceleration profiles, to provide the number and severity of conflicts at each conflict point. Vasconcelos et al. (2013) conducted a study on the number of conflicts in single-lane and two-lane roundabouts, as well as turbo roundabouts, using the AIMSUN and SSAM programs. Despite the limitations of existing simulation models, it was noted that SSAM serves as a valuable analysis tool for safety evaluations of new facilities [10]. Some of the studies that used SSAM in conflict analysis were conducted by [11-14].

The aim of this study is to determine the critical TTC value for conflicts caused by the entering and circulating vehicles at modern roundabouts. The data obtained from field studies were used as input in AIMSUN simulation program. The output trajectory files were processed using SSAM. The conflicts were initially identified manually and compared with SSAM results. The critical TTC value was then determined by modifying the TTC value in SSAM.

2 Methodology

2.1 Data collection

The study was conducted at three modern roundabouts in Izmir, utilizing Unmanned Aerial Vehicles (UAVs) for data collection. UAV-based systems offer cost advantages over manned air vehicles, with lower purchase, management, and operational costs. However, their application in traffic analysis is limited by factors such as weather conditions, technical instrumental problems, physical obstacles, and regulatory issues [15]. Aerial footage was captured using UAVs with assistance from traffic police. By flying one UAV while another remained in the air, uninterrupted footage was obtained, enabling traffic counting within the intersection without visual interruptions. The study utilized UAVs, specifically the DJI Phantom 3 Pro and DJI Phantom 4, to capture footage and accurately assess traffic volume.

2.2 Field studies

On December 22, 2022, a research study was conducted at the Guzelbahce intersection to determine the traffic volume during peak and off-peak hours. UAVs were flown between 13:35:43 and 14:25:43, as well as 15:33:52 and 16:33:52, ensuring continuous monitoring without any interruptions in the footage. The Hilltown intersection, located in Karşıyaka is situated next to Hilltown Shopping Mall and Sınav College on Flamingo Street.

To determine the vehicle counts at the intersection, aerial footage was captured on January 12, 2023, between 13:40-14:40 and 16:00-17:00. Another intersection, situated between 6108th Street and 6108/1st Street to 7004th Street in the Bornova district, is an uncontrolled roundabout. Located in an industrial area, it experiences a high volume of heavy vehicle traffic. On January 30, 2023, a total of 124 minutes of aerial footage was captured using a UAV between 13:17 and 14:20 in the afternoon, and from 16:06 to 17:07 in the evening. Figure 1 shows the intersections.

Figure 1 Observed roundabouts a) Guzelbahce, b) Hilltown, c) Sanayi

2.3 Time-to-collision

The time-to-collision (TTC) refers to the duration until two or more vehicles would collide under specific conditions. The use of TTC in the field of transportation began after Hayward's definition in 1972, which stated the time until two vehicles collide if no evasive action is taken [4]. TTC is an effective indicator in assessing traffic safety in studies related to traffic conflicts [17]. TTC can be calculated for 'F' (following vehicle) at instant 't' with respect to 'L' (leading vehicle) as shown in Equation (1).

$$TTC(t) = \frac{x_L(t) - x_F(t) - l_L}{\dot{x}_F(t) - \dot{x}_L(t)} \quad \forall \dot{x}_F(t) > \dot{x}_L(t) \tag{1}$$

where $\dot{x}$ denotes the speed, x the position, and l the vehicle length.

While the given formula is applicable for vehicle following situations, the need for a different method arises when considering angular collisions. Research [18] treated vehicles as rectangles and studied different configurations. As a result of this study, although there were 32 possible collision scenarios, they noted that only 10 collision patterns could occur. The method adopted for this study is based on determining which corner of a vehicle would reach the collision point first, depending on whether the collision angle is smaller or larger than 90 degrees. For further information, the readers are referred to [18].

2.4 Conflict analysis

The conflict counts were ascertained through the collective observations of three observers who meticulously reviewed the video footage. Traffic conflicts between entering and circulating traffic were manually calculated to enable comparison with SSAM outcomes. The most commonly used approach in identifying safety criteria is to utilize a post-processor on the data output obtained from a simulation model. FHWA (2008) has developed the Surrogate Safety Assessment Model for this purpose. The SSAM method computes safety surrogate metrics for each interaction between vehicles, assessing whether each interaction fulfils the conditions necessary to be classified as a conflict [9]. The simulation was conducted utilizing the Aimsun Next 22. The trajectory data obtained as output was subsequently subjected to processing through the employment of the SSAM methodology, thereby yielding the numerical representation of conflicts.

3 Findings

Using the data obtained from the traffic counts, a vehicle input was generated in the AIMSUN program. The traffic volume has been counted by categorizing vehicles into car, light commercial vehicle (LCV), bus, heavy vehicle (HV), and motorcycle. The traffic volume values incoming from each approach have been presented in Table 1 for off-peak hour observation, and in Table 2 for peak hour observation.

Table 1 Traffic volume at the observed roundabouts (off-peak hours)

Roundabout	**Car**	**LCV**	**Bus**	**HV**	**Motorcycle**
Guzelbahce Leg 1	515	18	10	28	12
Guzelbahce Leg2	735	78	0	38	15
Guzelbahce Leg3	634	68	9	30	26
Guzelbahce Leg4	90	0	0	0	0
Total	1974	164	19	96	53
Hilltown Leg1	546	19	0	1	19
Hilltown Leg2	17	0	0	0	2
Hilltown Leg3	101	9	0	9	18
Hilltown Leg4	400	14	0	3	18
Total	1064	42	0	13	57
Sanayi Leg1	481	11	5	127	23
Sanayi Leg2	209	84	2	133	12
Sanayi Leg3	323	82	8	150	8
Total	1013	177	15	410	43

Table 2 Traffic volume at the observed roundabouts (peak hours)

Roundabout	Car	LCV	Bus	HV	Motorcycle
Guzelbahce Leg 1	951	50	19	43	16
Guzelbahce Leg2	1499	100	4	30	11
Guzelbahce Leg3	1115	148	30	63	28
Guzelbahce Leg4	128	64	12	0	0
Total	3693	362	65	136	55
Hilltown Leg1	823	35	0	2	24
Hilltown Leg2	37	3	0	0	3
Hilltown Leg3	165	9	0	1	18
Hilltown Leg4	637	19	4	1	22
Total	1662	66	4	4	67
Sanayi Leg1	516	7	7	142	11
Sanayi Leg2	217	66	1	115	6
Sanayi Leg3	301	94	12	169	12
Total	1034	167	20	426	29

The study area was defined by overlaying a map image obtained from OpenStreetMap digital map platform with actual geometric data measured in the field. The number of lanes, the width of the lanes, entry and exit widths, inscribed circle diameter, speed limit, capacity, and turning movements were included in the model for each roundabout.

When comparing traffic volumes, the ‘Sanayi’ roundabout stands out due to its higher heavy vehicle traffic, particularly on the first leg. The intersection with the highest traffic volume is the ‘Guzelbahce’ intersection, followed by the ‘Hilltown’ intersection.

In Guzelbahçe roundabout a total of 106 conflicts, in Hilltown roundabout 42 conflicts, and in Sanayi roundabout 114 conflicts were observed. Based on these observed conflict numbers, the Time to Collision (TTC) value in SSAM was calibrated. This process aimed to identify the TTC value that aligns most closely with the actual conflict data, providing a TTC value that best matches the real conflict values.

In Table 3 the number of conflicts both observed and simulated with default and modified TTC values are presented. The defaults value is the initial TTC value used in the analysis which is 1.5 s. The calibrated TTC value is the one that has been adjusted through calibration to better match the observed conflicts.

In the Guzelbahce roundabout, where 106 conflicts were observed in the field, the calibrated TTC value of 1.58 seconds closely aligns with the observed conflicts. In the Hilltown roundabout, 42 conflicts were observed in the field, but after calibration, the TTC value that best matches this data is 3.00 s. The highest calibrated TTC was observed in Sanayi roundabout.

Table 3 SSAM results

Roundabout	Field observation	Default	Calibrated conflicts	
Guzelbahce	106	105	TTC:1.58 s	106
Hilltown	42	11	TTC: 3.00 s	38
Sanayi	114	11	TTC: 4.9 s	108

4 Results

Traffic conflicts were observed at varying levels across the studied roundabouts. A total of 106 conflicts were observed at Guzelbahçe roundabout, 42 conflicts at Hilltown roundabout, and 114 conflicts at Sanayi roundabout. These findings are consistent with prior studies suggesting that different roundabouts may experience distinct levels of traffic conflicts due to differences in design, traffic flow, and surrounding infrastructure [20].

Upon calibration of the TTC values using the SSAM, variations in the optimal TTC values for each roundabout were noted. Guzelbahçe roundabout, with 106 observed conflicts, exhibited a calibrated TTC value of 1.58 seconds, closely matching the observed conflicts. Hilltown roundabout, despite recording 42 conflicts, required a calibrated TTC value of 3.00 seconds to best align with the observed data. The highest calibrated TTC value (4.9 s) was observed in Sanayi roundabout, consistent with the higher number of observed conflicts at this location. The higher number of conflicts observed at the Sanayi intersection can be attributed to the prevalence of heavy vehicles compared to cars. This imbalance in vehicle types can lead to increased conflicts, particularly due to differences in maneuverability and braking capabilities between heavy vehicles and cars.

5 Conclusions

The conversion of intersection control types to roundabouts has demonstrated a capacity to diminish fatal collisions and injuries. While the decline in accidents constitutes a positive stride towards enhancing intersection safety, there remains untapped potential for further enhancement. Consequently, a more comprehensive examination of their safety performance is imperative, particularly in light of the anticipated increase in roundabout construction in the future [19].

The objective of this research is to ascertain the critical TTC value for conflicts arising from entering and circulating vehicles within modern roundabouts. The differences observed in the calibrated TTC values are believed to stem from variations in traffic volume, composition, and geometry. Previous studies could enhance the validity of results by conducting validation studies on intersections that possess characteristics representative of each individual intersection. The findings of the current study suggest that in intersections with lower heavy traffic volume, a TTC value closer to the default value aligns with the observed conflict count more closely.

The findings of this study corroborate previous research emphasizing the importance of calibrating TTC values to accurately represent observed traffic conflicts [7, 12, 13].

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References

[1] Grayson, G.B., Hydén, C., Kraay, J.H., Muhlrad, N., Oppe, S.: The Malmö Study: A Calibration of Traffic Conflict Techniques, Institute for Road Safety Research SWOV, Leidschendam, 1984.

[2] Chin, H.C., Quek, S.T.: Measurement of Traffic Conflicts, Safety Science, 26 (1997) 3, pp. 169-185

[3] Perkins, S., Harris, J.: Criteria for Traffic Conflict Characteristics: Accident Potential at Intersections, Research Publication GMR-718, General Motors Corporation, Warren, Michigan, 1967.

[4] Hayward, J.C.: Near-Miss Determination Through Use of a Scale of Danger, Highway Research Record, 384 (1972), pp. 24-34

[5] Burdett, B., Bill, A.R., Noyce, D.A.: Evaluation of Roundabout-Related Single-Vehicle Crashes, Transportation Research Record, 2637 (2017), pp. 17–26

[6] Sadeq, H., Sayed, T.: Automated Roundabout Safety Analysis: Diagnosis and Remedy of Safety Problems, Journal of Transportation Engineering, 142 (2016) 12, 04016062

[7] Gallelli, V., Iuele, T., Vaiana, R., Vitale, A.: Investigating the Transferability of Calibrated Microsimulation Parameters for Operational Performance Analysis in Roundabouts, Journal of Advanced Transportation, 2017.

[8] Ozbay, K., Yang, H., Bartin, B., Mudigonda, S.: Derivation and Validation of a New Simulation-Based Surrogate Safety Measure, Transportation Research Record, Journal of Transportation Research Board, 2083 (2008) 1, pp. 105-113

[9] FHWA: Surrogate Safety Assessment Model (SSAM) - Software User Manual, Federal Highway Administration, 2008.

[10] Vasconcelos, L., Silva, A., Seco, Á.: Safety Analysis of Turbo-Roundabouts Using the SSAM Technique, 6TH Annual Conference on Planning Research - CITTA 2013, pp. 1-15, Coimbra, Portugal, 2013.

[11] Guo, Y., Xiang, Q., Li, S., Zhang, T., Yao, R.: Impacts of Large Vehicles on Traffic Safety in Freeway Interchange Merging Areas and Improvement Measures, 6th International Conference on Transportation and Traffic Engineering -ICTTE 2017, Hong Kong, 1-3 July 2017.

[12] Essa, M., Sayed, T.: Transferability of Calibrated Microsimulation Model Parameters for Safety Assessment Using Simulated Conflicts, Accident Analysis and Prevention, 84 (2015), pp. 41-53

[13] Fan, R., Yu, H., Liu, P., Wang, W.: Using VISSIM Simulation Model and Surrogate Safety Assessment Model for Estimating Field Measured Traffic Conflicts at Freeway Merge Areas, IET Intelligent Transport Systems, 7 (2013) 1, pp. 68-77

[14] Shahdah, U., Saccomanno, F., Persaud, B.: Application of Traffic Microsimulation for Evaluating Safety Performance of Urban Signalized Intersections, Transportation Research Part C, 60 (2015), pp. 96-104

[15] Guido, G., Gallelli, V., Roganı, D., Vitale, A.: Evaluating the Accuracy of Vehicle Tracking Data Obtained from Unmanned Aerial Vehicles, International Journal of Transportation Science and Technology, 5 (2016) 3, pp. 136-151

[16] DJI Camera Drones, https://www.dji.com/global, 22.12.2023.

[17] Minderhoud, M. M., Bovy, P. H. L.: Extended Time-to-Collision Measures for Road Traffic Safety Assessment, Accident Analysis and Prevention, 33 (2001), pp. 89-97

[18] Jimenez, F., Naranjo, J.E., Garcia, F.: An Improved Method to Calculate the Time-to-Collision of Two Vehicles, International Journal of Intelligent Transportation Systems Research, 11 (2013) 1, pp. 34-42

[19] Orsini, F., Gecchele, G., Gastaldi, M., Rossi, R.: Collision Prediction in Roundabouts: A Comparative Study of Extreme Value Theory Approaches, Department of Civil, Environmental and Architectural Engineering, University of Padova, Italy, 2019.

[20] Alozi, R.A., Hussein, M.: Multi-Criteria Comparative Assessment of Unconventional Roundabout Designs, International Journal of Transportation Science and Technology, 11 (2022) 1, pp. 158-173