IJTE, Vol. 13, No. 3, Winter 2026, pp. 2291-2306
Research Paper

Roundabout Capacity: Investigating the Impact of the Weaving Length and Entry/Exit Radii with AIMSUN

Elham Bayzidi[1], Mahmoud Saffarzadeh[2,*], Hooman Rahimi[3]

Received: 2023/07/05 *Accepted: 2023/08/15*

Abstract

Roundabouts are recognized as effective traffic management solutions, offering advantages such as improved safety and reduced congestion compared to signalized intersections. However, exceeding the roundabout's capacity can result in decreased efficiency and safety. The capacity of a roundabout depends on various factors, including traffic flow rates, geometric design parameters, and traffic flow characteristics. This study investigates the influence of weaving length, entry radius, and exit radius on the capacity of a roundabout in Sanandaj, utilizing AIMSUN traffic simulation software. Statistical and computational methods are applied to analyze data obtained from parameter analysis. The findings emphasize that imbalanced dimensions and a limited perspective in transportation network design contribute to traffic congestion. Consequently, comprehensive consideration of geometric and behavioral aspects of users within the transportation network is crucial when designing roundabouts. This analytics-driven study provides valuable insights and patterns, enabling the development of original content that surpasses existing research, ultimately facilitating the identification of areas for improvement and effective decision making.

Keywords: Aimsun, Entry Radius, Exit Radius, Roundabout, Weaving Length

[*] Corresponding author: E-Mail: saffar_m@modares.ac.ir
[1] School of Built Environment, Faculty of Engineering, Islamic Azad University Central Branch, Tehran, Iran
[2] Department of Civil and Environmental Engineering, Tarbiat Modares University, Tehran, Iran
[3] Department of Civil Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran

1. Introduction

Roundabouts are a modern traffic management solution that aims to address issues commonly encountered in intersections and traffic circles. They were introduced in the 1960s in the United Kingdom, with a focus on giving priority to circulating traffic [Robinson, 2000].

Research has shown that roundabouts can offer several advantages over signalized intersections and four-way signalized junctions, including improved safety and reduced congestion [Roshanbin, 2017].

Roundabouts and other facilities with circulating traffic on roads are recognized as tools for reducing conflict points, and traffic congestion, serving as a simple traffic management method. Today, roundabouts are considered a type of urban at-grade intersection, and research conducted in advanced and innovative countries indicates that roundabouts can perform better, more effectively, and safer under certain conditions compared to signalized intersections. Under certain conditions compared to signalized intersections, but only if the roundabout has not exceeded its capacity. The advantages of roundabouts lie in their ability to enhance safety and minimize delays during non-peak traffic hours. Thus, when confronted with intersections characterized by high accident rates or significant delays, a roundabout sufficiency study is often recommended [Akcelik, 2017].

Capacity is a critical performance characteristic that greatly impacts the effectiveness of roundabouts. It serves as a key performance parameter in urban networks, influencing the overall efficiency of traffic flow. The capacity of a roundabout depends on multiple factors, encompassing the traffic flow rates at entry and exit points, pedestrian flow rates, driver behavior exhibited within the roundabout, and the geometric characteristics of the roundabout itself. Researchers and traffic centers from diverse countries have conducted extensive studies to investigate the capacity of modern roundabouts, yielding valuable insights that have formed the foundation for capacity models utilized in those respective regions.

Geometric design parameters play a crucial role in determining the performance of a roundabout. These parameters include the entry radius, which defines the curvature of the entry approach, the roundabout diameter, which determines the size of the central island, and the widened section length, which provides additional space for larger vehicles. Other important geometric design parameters include the entry width, which influences the ease of vehicle entry and exit, the entry angle, which affects the angle of approach for vehicles, the branch angle, which determines the angle at which vehicles exit the roundabout, and the number of circulatory lanes and entry street lanes, which determine the capacity of the roundabout.

Addition to geometric design parameters, traffic flow parameters also play a significant role in roundabout design. These parameters encompass the entry flow volume, which represents the number of vehicles entering the roundabout per unit of time, and the circulating flow volume, which indicates the number of vehicles already within the roundabout. Design speed, which defines the desired operating speed of vehicles within the roundabout, is another important traffic flow parameter. Traffic composition, which refers to the mix of vehicle types and sizes, is also considered in roundabout design as it affects the capacity and efficiency of the roundabout.

Furthermore, several other factors come into play when designing a roundabout. The location of the roundabout, whether it is in an urban or rural area, can influence design considerations. Design standards, traffic regulations, and lighting requirements must be adhered to when designing a roundabout to ensure compliance with safety and operational guidelines.

The geometric design of a roundabout necessitates striking a balance between various complementary design elements. The roundabout's performance must ensure safety by directing traffic at lower speeds. Many geometric parameters are influenced by the requirements of vehicle maneuvers. Hence, the design process of a roundabout entails optimizing the equilibrium between safety regulations, operational performance, and adherence to vehicle design standards.

Although the fundamental shape and characteristics of a roundabout are typically not influenced by specific locations, the final design outcomes can be affected by factors such as the surrounding environment, desired capacity, available space, requested number of lanes, design vehicle specifications, and other unique geometric features [Rodegerdts et al., 2010].

In recent years, transportation engineers have dedicated considerable research efforts to capacity assessment methods for both single-lane and multi-lane roundabouts. The growing popularity of these roundabouts has prompted researchers to develop comprehensive approaches for evaluating their capacity and analyzing traffic operations [Rodegerdts et al., 2010].

Extensive research has been carried out globally to establish capacity models specifically tailored to roundabout conditions. These models have been designed and calibrated for both single-lane and multi-lane roundabouts. However, the existing capacity models for multi-lane roundabouts are mainly suitable for roundabouts with two entry lanes and two turning lanes, typically featuring two entry lanes and two turning lanes. Consequently, these models cannot be regarded as valid or reliable when applied to roundabouts with three entry lanes and three turning lanes [Wang & Yang, 2012].

Capacity denotes the maximum rate of uninterrupted vehicle flow entering a roundabout through an entry approach within a specific timeframe, considering both geometric and traffic conditions. The assessment of capacity and delay values holds great significance in evaluating the performance of street networks, thereby playing a crucial role in roundabout management and traffic assignment models. Typically, the capacity of primary intersections acts as the primary controlling factor for overall vehicle movement volume within the entire network, and intersection capacity is determined by a combination of geometric, traffic, and control characteristics. However, controlling and evaluating capacity and delay values in signal-free roundabouts pose challenges due to their heavy reliance on driver behavior and adherence to traffic laws and regulations. Since capacity is not a constant value but a function of different traffic flow levels, it represents the service rate, or the speed at which queues are cleared, and directly impacts performance metrics such as delay, queue length, and stop frequency. This concept of capacity applies to both unsaturated and saturated traffic conditions, offering valuable insights into the operational efficiency of roundabouts [Transportation Research Board, 2010].

Figure (1) provides a visual reference for better comprehension of the conflict zone length, entry radius, and exit radius, enabling a more comprehensive understanding of these parameters.

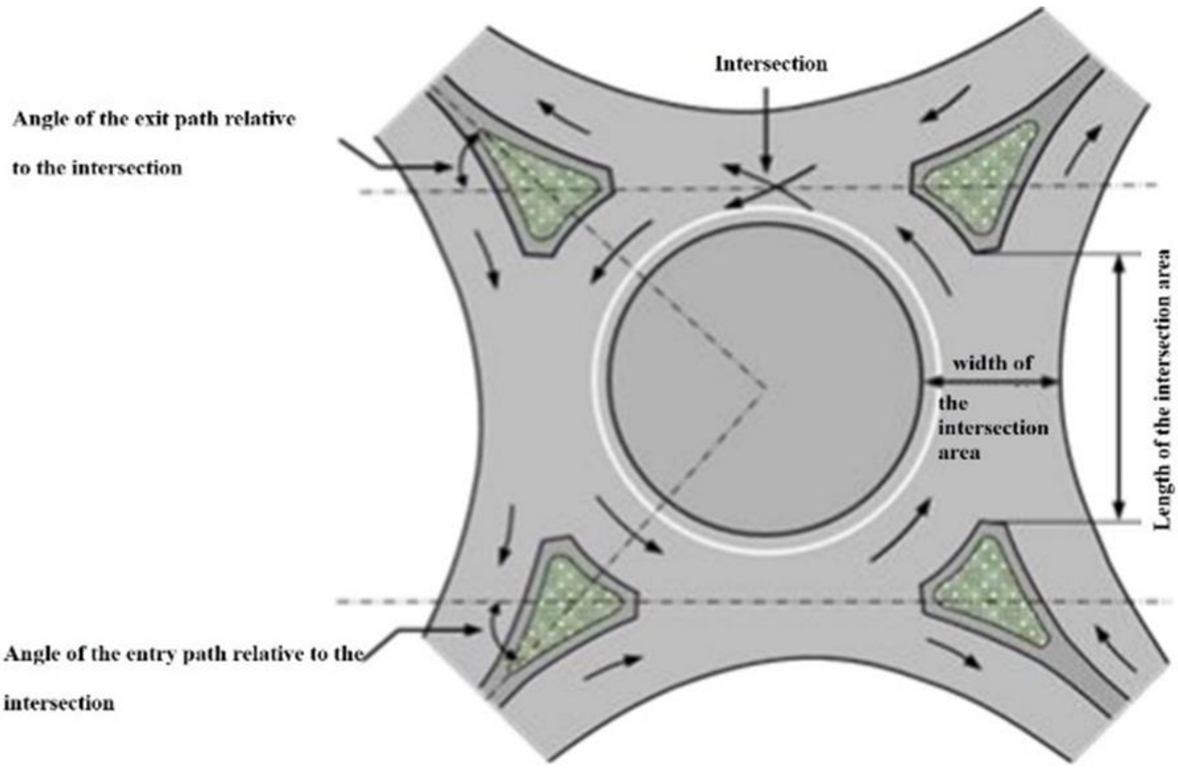

Figure 1. Length of the intersection area: Urban Street Design Guidelines, Volume 7 – Intersections

2. Literature Review

Extensive research has been conducted on the analysis of roundabout performance, and in this section, some studies and scientific research have addressed the geometric parameters of the roundabout and simulation using the AIMSUN software.

The study conducted by Divandari, Izadi, and Mohammadpour, aimed to improve traffic flow by modifying the geometric design of the Sheikh Atar Nishaburi Chalous roundabout using the AIMSUN simulator software. The results of their research showed a significant improvement in all aspects of traffic flow when the weaving length was increased. [Divandari, Izadi, and Mohammadpour, 2019].

In their study, Rahimov et al. focused on the development of control delay models specifically for multi-lane roundabouts in Kermanshah. They conducted simulations on different roundabouts that had varying numbers of entry and circulating lanes, as well as different central island radii. The researchers utilized SPSS22 software and employed various methods including nonlinear regression, neural networks, weighting analysis, categorical regression with optimal scaling, and least roundabouts analysis to model and validate the delay estimates. The model with the highest R2 value was chosen as the final model, indicating its better fit to the simulated data [Rahimov, Saffarzadeh and Arjmandi, 2021].

On the other hand, Abdi and Mahdavi-Kouchkasraee analyzed the operational characteristics of roundabouts, focusing specifically on the impact of geometric design. They employed the AIMSUN traffic simulation software to evaluate the traffic indicators such as delay time, speed, and capacity. By comparing the values obtained from the AIMSUN traffic simulation, the researchers were able to assess the effect of the central island diameter and weaving width as the number of lanes which their findings show improvement in the traffic flow in case of increasing the mentioned parameters [Abdi and Mahdavi-Kouchkasraee, 2018].

Selatahneh et al. conducted a comprehensive feasibility study to assess the effects of removing a roundabout on the traffic performance of the urban road network in Rasht, specifically focusing on the Seyghalan Roundabout. The study investigated the impact of two specific interventions: the removal of the roundabout itself and the closure of the direct access route and left turn for the two east-west approaches. The results of their study revealed significant changes in traffic conditions following the removal of the roundabout and the implementation of the interventions. Access to the affected area experienced a notable decrease of 32 percent, indicating a reduction in the overall traffic volume. Additionally, the queue length, which represents the length of vehicles waiting in line, exhibited an 8 percent decrease [Selatahneh et al., 2015].

Kazemifard et al. conducted a study focusing on enhancing traffic conditions through the utilization of AIMSUN simulation software. The study employed the AIMSUN simulator software for microscopic modeling. The findings revealed that the inclusion of U-Turns on approaches prior to the roundabout significantly increased the speed rate and traffic flow within the roundabout. This indicates that incorporating U-Turns as a feature can effectively improve the overall performance of the roundabout in terms of speed and traffic movement [Kazemifard et al., 2016].

Davoudian-Izadkhah and Bargegol investigated the capacity of urban roundabouts and the influential factors in Rasht. In this research, using collected data such as entry and circulating volumes, acceptable and unacceptable clearance distances, as well as pedestrian traffic flow rates in three urban surface fields, mathematical analysis and regression relationships were employed to determine the capacity of these fields based on the impact of traffic volume, driver behavior, and pedestrian flow on their entry volume [Davoudian-Izadkhah and Bargegol, 2014].

Shafabakhsh et al., addressed the geometric design improvement of the Namazi Shiraz intersection using the AIMSUN simulation software. In this study, the Namazi Shiraz intersection was simulated using the AIMSUN software, and the parameters affecting traffic flow, such as traffic volume, flow rate, delay, and passing flow, were examined based on the software exits [Shafabakhsh et al., 2013].

Gallelli, Vaiana, and Iuele conducted a comprehensive study comparing the speed profiles of intersections with varying geometric characteristics. They employed a combination of simulation and laboratory experiments to investigate the impact of these characteristics on intersection performance. The research findings provide valuable insights regarding optimal ranges for approach speed, the necessity of implementing reduced speed zones, recommended values for critical gaps, and the significance of speed control within the circulatory roadway [Gallelli, Vaiana, and Iuele, 2014].

Five years later, Gallelli and Vaiana explored the safety enhancements achieved through the conversion of a standard roundabout into an unbalanced flow turbo roundabout. Their research findings revealed that the implementation of the proposed egg turbo roundabout design resulted in significant improvements in both operational efficiency and safety performance compared to the traditional multi-lane roundabout configuration. It is important to note that the conclusions drawn by the authors are limited to the specific case study examined in their research [Gallelli, Vaiana, 2019].

Marfani et al. conducted a study focusing on enhancing traffic conditions at urban road intersections. The primary aim of this research was to investigate the issue and propose viable solutions. The collected data revealed that the current traffic volume exceeds the simulated capacity of 4738 vehicles per hour, which surpasses the recommended traffic capacity of

3,000 Passenger Car Units (PCU) per hour set by the Indian Road Congress [Marfani et al., 2018].

Another comprehensive study on intersection capacity, considering different traffic conditions highlighted the importance of circulating traffic flow as a primary factor. Through the analysis, the researchers discovered that the entry capacity of intersections is influenced by circulating traffic flow, central island diameter, and circulating roadway width. Notably, they found that the central island diameter has a substantial impact on the entry capacity, whereas the effect of circulating roadway width remains consistent beyond a width of 11 m [Ahmad and Rastogi, 2018].

According to the study conducted by Zhao, Khatak, and Sampson, the implementation of roundabouts led to substantial improvements in safety. Interestingly, the analysis indicated that roundabouts on rural high-speed roadways yielded safety benefits comparable to those observed in urban areas and economic evaluation provides valuable insights into the cost-effectiveness of implementing roundabouts as a safety measure [Zhao, Khatak, and Sampson 2015].

Al-Madani addressed the capacity planning of large intersections under high traffic volumes. Estimating the entry capacity of intersections largely varies between the two methods in terms of their entry requirements, model complexity, assumptions, and estimation accuracy. Several existing models for estimating capacity at the branch entries of large intersections were tested and compared in this study. Three models were developed to estimate the capacity of multi-lane intersections [Al-Madani, 2013].

Sone conducted a comprehensive study examining the influence of behavioral, geometric, and traffic characteristics of heavy vehicles on the capacity and emissions of intersections using the VISSIM simulator, analyzing a wide range of roundabout scenarios. The research findings revealed that larger radii had a significant positive impact on capacity, leading to increased traffic throughput. Conversely, higher truck percentages and longer critical gaps had a negative effect on capacity, resulting in reduced traffic flow [Sone, 2010].

Polus and Vlahos evaluated signalized intersections and roundabouts. In this study, they assessed and compared a single-lane roundabout with an unsignalized intersection and a signalized intersection. Their findings revealed that the two-way stop-controlled intersection performed best when major road volumes were low. On the other hand, the pre-timed signal performed most effectively for high volumes. In the case of mid-range volumes falling between the two extremes, the roundabout demonstrated the best performance [Polus and Vlahos, 2005].

By classifying the similarities as shown in Table (1), the study indicates that roundabouts are best for low to mid-range flow rates, but after that the implementation of the roundabouts with no modifications has a reverse influence on the traffic characteristics specially LOS.

Also, the findings reveal that the geometric design of the roundabout can be classified as two aspects of the overall shape (e.g., oval or turbo or teardrop) and proportional parameters of the roundabout.

Table 1. Literature Review Matrix

Class	Study by	Criteria	Result
Concept	Zhao, Khatak, and Sampson, 2015	Implementation of roundabouts	Safety improvements
Geometry improvement	Gallelli, Vaiana, and Iuele, 2014	Reduction of speed up to 15 km/h	Improvement of traffic flow

Class	Study by	Criteria	Result
	Kazemifard et al., 2016	Incorporating U-turns before the roundabout	Improvement of traffic flow
	Divandari, Izadi, and Mohammadpour, 2019	Increasing weaving length	Improvement of traffic flow
	Abdi and mahdavi-kouchkasraee, 2018	Increase central island dia. And weaving with	Improvement of traffic flow
	Sone, 2010	Larger radii roundabout	Positive impact on capacity
Shapes improvement	Shafabakhsh et al., 2013	Shape of the roundabout	Traffic improvement with teardrop shape
	Gallelli, Vaiana	Turbo roundabouts	Improved efficiency and safety
	Davoudian-Izadkhah and Bargegol, 2014	Turbo roundabouts	Up to 150 percent increase in capacity
Limitations of the roundabouts	Marfani et al., 2018	Roundabout performance range	Up to 3000 pcu per hour
	Ahmad and Rastogi, 2018	Dia. Up to 80m and weaving width up to 17m	Increase the capacity only up to the limits
	Polus and Vlahos, 2005	Roundabouts	Best performance for mid-range volumes
	Selatahneh, 2015	Over 6500 CPU per hour flow roundabout	Implementation of other interchanges solutions shows improvement

3. A Review of Capacity Models

Effective design of roundabouts requires analyzing their maximum capacity, and since the 1970s, a series of models have been developed worldwide to determine roundabout capacity, most of which rely on extensive empirical data. However, given the fundamentally different principles and especially the geographical roots of these models, it is necessary to have a clear understanding of their limitations and their application in modern societies.

Therefore, the capacity of a roundabout can be considered a function of geometric parameters, demand flows, as well as vehicle and driver characteristics. Several capacity determinations models have been developed worldwide, which can be classified into the following categories based on their primary and fundamental methods:

- Empirical models: Based on the relationship between geometric parameters and actual measured capacity.

Acceptable delay gap models: Based on understanding driver behavior.

- Microscopic Traffic Simulation Models: Based on modeling the kinematics of the interactive effects of vehicles.

3.1. Empirical Capacity Models

Empirical regression models are developed based on multivariate regression analysis and the establishment of mathematical relationships between actual capacity (Q_e), traffic flow (Q_c), and other dependent variables that significantly affect capacity. The relationships between Q_e and Q_c are usually assumed to be linear ($Q_e = \alpha - \beta Q_c$) or exponential ($Q_e = \alpha e^{(\beta Q_c)}$). The LR942 regression model is considered the best fully empirical model for roundabout capacity worldwide. This model is the standard model in England and forms the core of many roundabout analysis software tools such as ARCADY and RODEL.

This model is based on six geometric parameters: entry width (e), entry angle (∅) and radius (r), half the entry path width (ν), external circular diameter at the entry (D), and the effect of the opening line length (flare) (L') at the entry location and the flare rate (S).

Considering the mentioned variables, the linear regression model is determined by equation (1):

$$Q_e = k\,(F - vf_{(c)}\,Q_c),\ f_c\,Q_c \leq F \quad (1)$$

where Qe and Qc represent the entry capacity and traffic flow, respectively, measured in pcu/h (passenger car units per hour). The parameters in equation (1) are obtained from equations (2 to 7).

$$K = 1 - 0.00347\,(\emptyset - 30) - 0.978\,(1/r - 0.05) \quad (2)$$

$$F = 303 \times X_2 \quad (3)$$

$$X_2 = \nu + ((e-\nu)/(1+2S)) \quad (4)$$

$$S = (1.6\,(e-\nu))/L' \quad (5)$$

$$f_c = 0.2 \times t_D\,(1+0.2X_2) \quad (6)$$

$$t_D = 1 + 0.5/(1+e^{((D-60)/10)}) \quad (7)$$

3.1.1. The Girabase Model (France)

Several linear regression models exist in France, among which the SETRA and CETRU models can be mentioned. Based on statistical analyses, the entry capacity (C) is derived from equation (8):

$$C = \left[\frac{3600}{t_f}\left(\frac{W_e}{3.5}\right)^{0.8}\right] \times e^{C_b Q_d} \quad (8)$$

where t_f is the time gap in seconds, W_e is the entry width in meters, C_b is the environment adjustment coefficient for urban and non-urban areas, and Q_d is a function of traffic flow, representing the exit in the same unit, along with geometric parameters.

3.1.2. Highway Capacity Model in the United States (HCM2000)

This model utilizes two-time parameters, critical time gap and follow-up time, which are determinants of field capacity and obtained from traffic studies in the target area. The capacity equation for the field is as follows (equation 9):

$$C_a = \frac{V_C\,.\,e^{\left[\frac{-V_C.t_c}{3600}\right]}}{1 - e^{\left[\frac{-V_C.t_f}{3600}\right]}} \quad (9)$$

Equation (9) represents the following:
Ca = Capacity of the selected entry roadway (pcu/h)

V_c = Traffic flow rate for the selected roadway (pcu/h)

t_c = Critical time headway in seconds

t_f = Time to pass through the vehicle queue in seconds

3.1.3. Brilon-Wu Model

The model used in the book "Capacity of German Roads" is based on the principles of acceptable travel time and queueing theory, and it is derived from the number of entry lanes (n_e) and circulating lanes (n_c). Equation 10 represents this model, where Δ represents the minimum time gap within a cluster of vehicles.

3.1.4. Austroads Model

In Tanner's equation, it is assumed that t_c and t_f are constants, and the distribution of inter-vehicle gaps in the main flow (flow in circulation around the field) is random, although this is not true. The movement of many vehicles occurs in two modes. One mode is in groups and batches, where each vehicle moves closely with the vehicle in front of it and interacts with other vehicles; the second mode is free flow, where each vehicle moves without interaction with other vehicles. Therefore, Troutbeck modified Tanner's equation by assuming an exponential distribution of transferable Cohen, which is presented as equations (10), (11) and (12);

$$Q_e = 3600\left(1 - \frac{\Delta Q_c}{n_c 3600}\right)^{n_c} \times \frac{n_e}{n_f}\,e^{-\frac{Q_c}{3600}\left(t_c - \frac{t_f}{2} - \Delta\right)} \quad (10)$$

$$Q_e = \frac{3600(1-\theta)q_c e^{-\lambda(T-\Delta)}}{1 - e^{-\lambda T_0}} \quad (11)$$

$$\lambda = \frac{(1-\theta)q_c}{1 - \Delta q_c} \quad (12)$$

where:

Q_e = Entry capacity (pcu/h)
q_c = Field circulating traffic volume (pcu/h)
θ = Grouped vehicle ratio
Δ = Minimum inter-vehicle gap in the sequential traffic sequence in the circulating roundabout, assumed to be 2 seconds for one-lane roundabouts and 1 second for two-lane roundabouts
t_c = Critical passage time (s)
t_f = vehicles Sequence time gap of in the entry queue (s)

3.2. Microscopic Simulation Models

A microscopic simulation model is based on the movements and interactions between each vehicle in a network of links, nodes, and connections. The movements of vehicles resulting from an acceptable time gap, vehicle following, lane changing, and other models are generally calculated for each vehicle at each time. Driver behaviors parameters such as critical passage time and random processes such as vehicle generation are assigned using the Monte Carlo method and specific probability distributions. The exit results attempt to reflect the traffic characteristics in the real world.

There are many simulations software available for traffic modeling, such as S-Paramics (2011), Aimsun (2011), Synchro (2011), and Vissim, with S-Paramics being one of the most reliable ones.

One of the benefits of microscopic simulation models is the control of demand flow and circulating movements through parametric studies. They have also been used in roundabout research to model the effects. Furthermore, they have been used for the development and validation of macroscopic simulation models such as SIDRA.

Macroscopic capacity models have obtained data through regression from microscopic simulation models instead of field data. Simulation models play an important role in modeling the effects of congestion on capacity. The role of simulation models in roundabout capacity modeling has been demonstrated through the development of the Swiss Bovy-Tan capacity model.

4. Research Methodology

"Since this study is a case study, it falls under the descriptive research methodology, using the Aimsun software. The case study was a roundabout located northeast of Sanandaj.

4.1. Data Collection

Accurate and reliable data collection is essential for ensuring the integrity of the study. To achieve this, we considered a one-week duration that accounts for maximum daily traffic, while also avoiding non-harmonic traffic during vacations and unusual situations. Experienced staff from Relevance Engineering Consulting conducted the data collection, under the supervision of supervisors, to ensure high-quality field observations. Additionally, predesigned forms were used to facilitate systematic data collection.

4.2. Simulation Parameters

The justification and selection of appropriate simulation parameters are crucial for accurate modeling and analysis. Parameters such as delay time, density, flow rate, travel time, and operational speed were carefully considered and justified based on their relevance to the research objectives.

For this study, we utilized the AIMSUN software for analyzing and calculating simulation parameters after data entry. This software provides a reliable platform for simulation and enables efficient analysis of field performance.

As mentioned earlier, there are many software available for traffic modeling, and Aimsun is one of the most reputable ones. In this research, we utilize microscopic simulation models to investigate field capacity.

Traffic simulation is one of the newest engineering sciences in the field of transportation and traffic and is considered a requirement for approving traffic plans in countries with advanced traffic systems. Simulation is one of the most powerful and reliable tools for research in operations and system analysis. Simulation can be defined as the process of designing a model of a real system and using it to understand the system accurately or evaluate various methods for system performance.

The Aimsun software enables simultaneous macroscopic, mesoscopic, and microscopic simulations. In this research, using the mentioned software, the roundabout was simulated with different entry and circulating traffic volumes, and based on the software exits, models were developed to calculate roundabout capacity for constant traffic values. In the simulation process and model construction, delay time, density, flow rate, travel time, and operational speed were assumed for non-congested and non-homogeneous conditions, with a maximum speed of 30 km/h. The studied roundabout has been considered asymmetrical and divided into three branches with unequal approaches. The entry traffic has been considered based on the traffic statistics for right and straight movements, as well as left turns. The roundabout has been simulated by adjusting the entry and exit radii and the length of the intersection area according to the existing conditions.

The research stages are briefly described as follows:

1. Gathering traffic statistics of the roundabout and its approaches during peak hours.
2. Identifying parameters and variables affecting delay, density, flow intensity, speed, travel time, and capacity of the roundabout.
3. Simulating the traffic of the roundabout under different geometric conditions and constant traffic, and calculating the mentioned parameters.
4. Presenting final models for capacity and other examined parameters.
5. Construction and development.

Next, a summary of simulation results and roundabout studies is provided.

4.3. Field Studies

The studied roundabout has internal and external diameters of 42 and 72 meters, an intersection area width of 14 meters, and a weaving area with a length of 45 meters. The entry and exit radii are 15 meters, as shown in Figure 2. The measurements of capacity, delay, density, flow intensity, speed, and travel time were taken under different geometric conditions, and these measurements are referred to as the existing conditions. The field measurements were conducted simultaneously for entry, exit, and circulating traffic during peak hours.

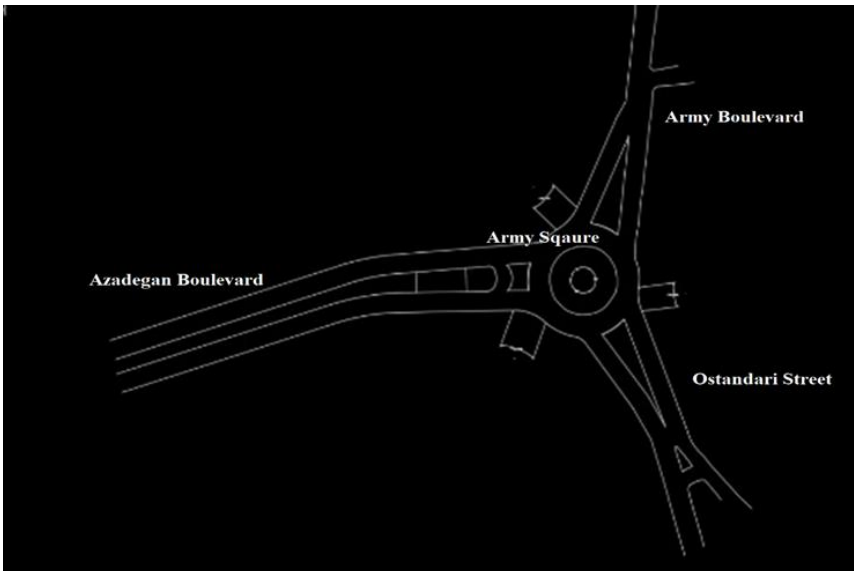

Figure 2. The current status of the Roundabout

4.4. Modeling

While the Aimsun software can simultaneously calculate results with multiple parameter changes, we initially examined single-variable scenarios to evaluate the impact of each parameter. In other words, the dimensions and other features are kept constant, and modeling is performed. After identifying the effects of each variable separately (considering the possibility of parameter interactions), scenarios involving more than two variables will be investigated to cover all possibilities and be studied. Figure 3 illustrates the program execution view.

Apart from the mentioned components, it is necessary to mention the constant flow of traffic in all scenarios. While driver behavior, pedestrian behavior, peak traffic, and lighting also have an impact on the results, they are not addressed in this research. Therefore, only by maintaining the flow of traffic in the scenarios', suitably controlled conditions have been considered.

The targeted roundabout will be modeled using the mentioned assumptions and variable parameters. The overall models in this research are presented in Table (2), considering the existing conditions and the gathered traffic statistics. Fourteen scenarios have been examined in this research.

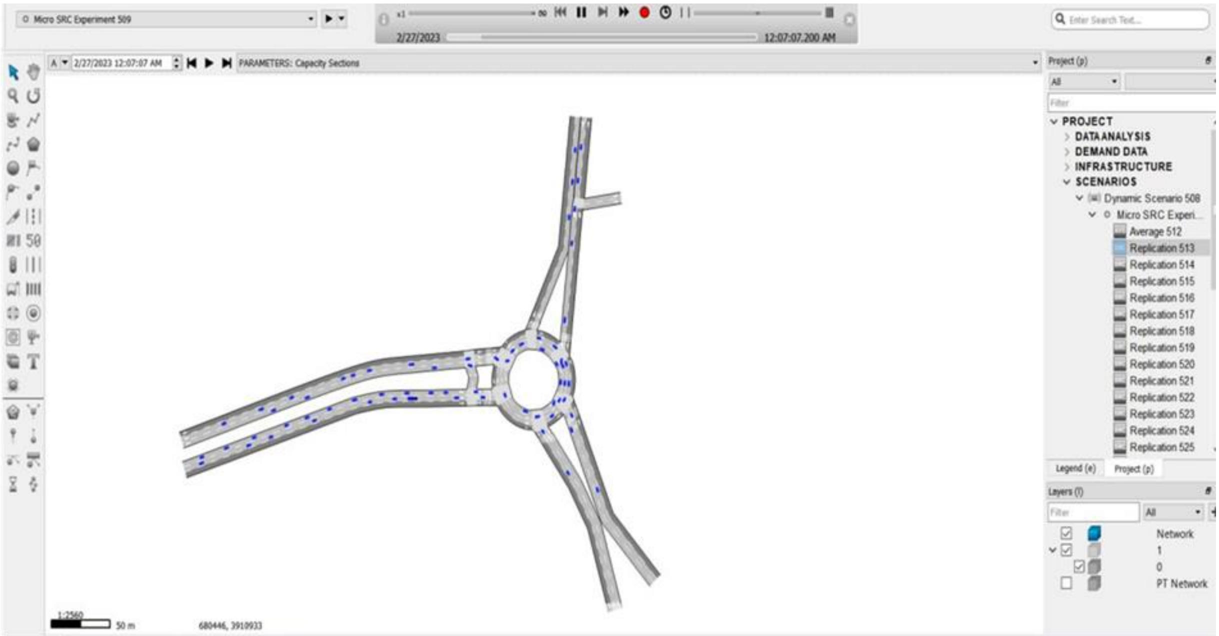

Figure 3. Scenario implementation

Table 2. Geometric properties of the curent situation and scenarios

Model and Scenarios	Entry Radius	Exit Radius	Weaving Length
Current State	15	15	45
1	15	5	45
2	15	30	45
3	5	15	45
4	30	15	45
5	15	15	35
6	15	15	60
7	5	30	45
8	30	30	45
9	15	30	35
10	15	30	60

Model and Scenarios	Entry Radius	Exit Radius	Weaving Length
11	5	30	35
12	5	30	60
13	30	30	35
14	30	30	60

4.5. Model Validation

To ensure model reliability, a second run was conducted on a separate device. This validation process aimed to check the consistency and accuracy of the daily results and data. The comparison between the two entries revealed differences of less than 5 percent, indicating the high reliability of the model.

By incorporating these improvements, the study ensures accurate and reliable data collection, appropriate selection of simulation parameters, and model validation, which strengthens the overall integrity and validity of the research.

5. Results

While the speed limit around the roundabout is 30 km/h, since a road segment is affected through the roundabout, the velocity limit is assumed to be 50 km/h in AIMSUN for the current state of the roundabout as a part of the bigger segments of the road, which has a delay of 47.7 s is the result of such a condition as shown in Table (3).

Table 3. Current State

Speed km/h	Delay s/km	Density veh/km	Crossing time s/km
47.7	20.96	34.58	47.7

Compare to the Stop-Controlled delay criteria the Level of Service (LOS) shown in Table (4), the current state of the roundabout is almost Level F [Rodegerdts et al, 2010].

In this study, we investigated the set of traffic indicators by changing parameters such as entry radius, exit radius, and weaving length. Among the examined scenarios, the scenario of increasing the entry radius, increasing the exit radius, and reducing the weaving length provided the highest performance and capacity compared with other scenarios and the existing condition.

Table 4. LOS Criteria

Control Delay (s/veh)	LOS by Volume-to-Capacity Ratio	
	v/c < 1.0	v/c > 1.0
0–10	A	F
>10–15	B	F
>15–25	C	F
>25–35	D	F
>35–50	E	F
>50	F	F

After running each scenario in AIMSAN, results charts and averages according to the warm-up and running time are separately represented and exported to a specific file format. All results were controlled by remodeling all scenarios once again and running the same conditions for warm-up and running times.

To illustrate the overall results of the capacity, Table (5) has been prepared and sorted from maximum to minimum. For easier understanding, the visual features and the light-shadow pattern have been used to represent the values in each column, which on one hand, the descending sequence of roundabout capacity after sorting is indicated, and on the other hand, the influence of parameter changes on each other in the mentioned scenarios is displayed.

Table 5. Based on the Scenarios capacity and Current State

Scenario number	Capacity (veh/h)	Entry radius (m)	Exit radius (m)	Weaving length (m)	Speed (%)	Delay (%)	Density (%)	Crossing time (%)
8	6120	30	30	45	4	16	12	6
13	5514	30	30	35	29	-64	-24	-28
4	5466	30	15	45	-16	93	47	38
14	5417	30	30	60	-13	76	43	30

Scenario number	Capacity (veh/h)	Entry radius (m)	Exit radius (m)	Weaving length (m)	Speed (%)	Delay (%)	Density (%)	Crossing time (%)
2	5346	15	30	45	7	-16	-6	-7
Current state	5295	15	15	45				
10	5271	15	30	60	-23	86	42	34
9	5135	15	30	35	-20	72	28	30
6	4891	15	15	60	-33	150	58	60
3	4503	5	15	45	-8	16	-9	7
12	4466	5	30	60	-3	5	-11	1
7	4434	5	30	45	-9	20	-8	8
11	4308	5	30	35	-20	57	2	24
5	3498	15	15	35	-43	460	88	189

On the left side of Table (5), the comparison of scenario performance with the existing condition is shown for the percentage of increase or decrease in each of the listed indicators. Negative numbers indicate the percentage of decrease, and positive numbers indicate the percentage of increase. Finally, the three indicators of 'delay, density, and passage time through the roundabout,' which have negative values indicating better performance, are placed in the three leftmost columns.

6. Conclusion

To ensure accurate results, diligent efforts were made in data collection, loading the data into the Aimsun software, and intelligently selecting and modeling parameters using the regression model. The research also employed reassessment and final validation at each stage, including mapping the current state, statistical data collection and traffic counting, and simulation of the current state. The controlled environment and individual parameter analysis contributed to a comprehensive understanding of the roundabout's performance.

However, it is important to note that the impact of the weaving length parameter is dependent on other factors, such as changes in other components, entry width, and branch angles. Increasing the weaving length alone does not necessarily lead to improved performance or increased capacity. However, the design process should consider the consistency of changes in the roundabout and the urban road network to avoid exacerbating issues when relocating traffic nodes.

In summary, the key findings of this study are as follows:

- Entry Radius:

Decreasing the entry radius from 15 meters to 5 meters results in a 16 percent average decrease in roundabout capacity.

Increasing the entry radius from 15 to 30 meters leads to an average 2 percent increase in roundabout capacity.

- Exit Radius:

Reducing the exit radius from 15 meters to 5 meters causes a 35 percent decrease in roundabout capacity.

Increasing the exit radius from 15 to 30 meters, while keeping other variables constant, results in an average 1 percent increase in roundabout capacity.

- Weaving Length:

Decreasing the weaving length area from 45 meters to 35 meters, while other parameters are constant, leads to a 35 percent decrease in traffic intensity.

Increasing the weaving length from 45 to 60 meters, while keeping other variables constant, results in a 9 percent increase in traffic intensity. However, the relationship between the weaving length and traffic intensity is not linearly proportional in all scenarios, suggesting the influence of other parameters.

Considering the LOS, the ideal scenario would be Scenario 13, which involves increasing the exit radius, increasing the entry radius, and decreasing the weaving length. Although Scenario 8 shows higher capacity, according to table (4) its delay of 55.22 s represents a "F" LOS.

Besides all, the findings indicate that increasing the entry and exit radii lead to a modest increase of 2 percent and 1 percent in capacity, respectively, in the single-variable case, which does not have a significant impact on the capacity of the roundabout, while decreasing each radius results in a noticeable decrease in capacity, specifying the current state of the roundabout operating optimally.

Moreover, it is worth noting that there are no specific roundabout capacity criteria in the "Street Design Guidelines, Part 7: Intersections" or other relevant national guidelines. However, when comparing the roundabout capacity with criteria from other countries like India, it surpasses the recommended traffic capacity of 3,000 PCU per hour set by the Indian Road Congress (IRC). [Marfani et al, 2018]. Therefore, this study concludes that even with the implementation of Scenario 13, the roundabout's traffic characteristics will not meet the requirements, and a new traffic management solution or a combination of roundabout and other solutions should be implemented.

By incorporating these findings, transportation planners and engineers can make informed decisions to optimize the roundabout design and improve traffic flow. It is crucial to consider the interplay of various parameters and their effects on capacity and performance.

For future studies, it is recommended to categorize the requirements of roundabouts according to the flow rate of the relevant planning period, LOS, and design speed specific to each type of intersection. Additionally, collaborating with regulatory and guideline organizations is advisable to implement their validations and effectively finalize the obtained results for regulatory purposes.

7. Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

8. Acknowledgments

The authors would like to acknowledge Barzak-sazeh Engineering Consulting for their efforts in data acquisition.

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