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RESEARCH PAPER

Appropriate Intersection Design Type Based on TOPSIS Multiple Criteria Decision Method with AIMSUN Mesoscopic Simulation

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Abstract
The increasing world population has also increased the demand for vehicles and brought along various problems such as traffic delays, accidents, and air pollution. In addition, the increase in the number of vehicles causes an increase in the time spent at intersections, negatively affecting people's quality of life, distracting drivers, and unsafe driving practices. Moreover, greenhouse gas emissions, including CO_2 and NOx from vehicles, cause climate change and deterioration of air quality. To solve these problems, in this study, seven signalized intersections on a corridor in the city center of Erzincan province were examined. Using the Aimsun traffic simulation program, factors such as CO_2, VOC, NOx emissions, queue length, delay time, travel time, and speed were evaluated. Using one of the multiple criteria decision methods, the TOPSIS method, the ideal scenario was determined based on the simulation results, considering the construction costs. The study revealed significant improvements in several parameters. CO_2 emissions were reduced by 10%, delay time by 35%, VOC emissions by 14%, NOx emissions by 13%, queue length by 35%, delay by 38%, and travel by 19%. Furthermore, the speed was increased by 15%.

Keywords AIMSUN · Simulation · Intersections · Signalization · Multi-criteria decision · TOPSIS

1 Introduction

Transportation takes an essential place in human lives as it involves the movement of people and goods between different locations. Transportation systems need to be designed considering reliability, affordability, and comfort. However, with the growing population and economic progress, the number of vehicles on the roads has increased significantly. This surge in vehicle numbers has caused several undesirable consequences, including traffic accidents, travel delays, environmental pollution, and pavement failures (Hojati et al. 2013). These issues have notably impacted urban transportation systems.

Intersections can constitute significant challenges regarding traffic flow as they are points where different traffic streams intersect. These intersections are the conflict points for the vehicles moving in different directions. Intersections are highly prone to traffic issues due to the complexity of managing multiple flows concurrently.

In urban transportation, intersections play a crucial role and become focal points for traffic delays and accidents commonly. Studies suggest that about %70 of the delays in urban transportation can be attributed to intersections. Furthermore, statistics indicate that %40 to %60 of traffic accidents occur at urban intersections (Erol 2018). Therefore, efficient management and design of intersections are crucial to reduce traffic problems and improve overall transportation safety and efficiency in urban areas (Baş et al. 2020).

Simulation programs have been used more widely in intersection design and analysis in recent years. These simulation programs, such as Aimsun, Dynamit, Vissim, and Transims, have expedited comparing traffic performances and aided in making informed decisions. Using simulation programs, transportation planners and engineers can model the existing situation of the intersections and create alternative traffic scenarios. Using these alternative scenarios, the factors affecting intersection performance can be evaluated. By analyzing the simulated results, different design options, signal timings, or geometric configurations can be

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evaluated, and decisions can be made to optimize intersection efficiency and safety (Park and Schneeberger 2003; Huang et al. 2023). Using simulation programs in intersection design has proven reliable in reducing potential risks and improving traffic flow, resulting in more efficient transportation networks (Savaş 2019; Liu et al. 2023).

This study used the Aimsun simulation program to compare the current condition along the study corridor with the created alternative scenarios. Simulation programs like Aimsun allow researchers to analyze and evaluate different scenarios providing valuable insights into traffic performance.

In applications involving multiple alternatives, different criteria are established to evaluate the alternatives and compare them with each other. Based on these criteria, the most suitable alternative is selected (Demiriz et al. 2021). Various multi-criteria decision-making methods are commonly employed to aid in this decision-making process, including Promethee, Electre, AHP (Analytic Hierarchy Process), and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution). These methods help in considering multiple criteria, such as safety, capacity, environmental impact, and cost, to identify the ideal solution that satisfies the desired objectives. The mentioned study used the TOPSIS method to determine the most appropriate alternative scenario (Hwang et al. 1981). The versatility and adaptability of the TOPSIS method make it a popular choice in decision-making processes, as it provides a systematic framework for evaluating and ranking alternatives. It's simplicity and broad usage areas contributed to its widespread acceptance and applicability across different domains (Çilingir 2019).

There are several studies in literature that scope traffic simulation approaches and decision-making methodologies. Erol (Erol 2018) employed the TRANSYT-7 F program to evaluate the change in intersection performance via Vissim in the signaling direction to reduce the negative effects of delays at urban intersections. Demiriz et al. (Demiriz et al. 2021) used AHP method to evaluate the existing conditions and four potential scenarios for the main arteries in city center. Savaş (Savaş 2019) studied pedestrian and vehicle interactions at a grade separated intersection to improve safety and reduce delays. In order to increase the efficiency of bus lines, Forouzandeh et al. (Forouzandeh et al. 2022) evaluated the performance of the improved situation with the existing situation with Aimsun software. Alemdar et al. (Alemdar et al. 2021) utilized AHP method to evaluate the designs generated with Vissim for intersection analysis in the corridor. The Topsis decision-making method was utilized to identify the optimal design. The findings indicated that improvements of up to 80%, leading to increased energy efficiency, diminished environmental impact, time savings, and cost reductions. Garmei et al. (Garmei and Kashi 2019) analyzed the calibrated and uncalibrated scenarios by assessing the volume of pedestrians and vehicles to investigate the heterogeneous traffic conditions of pedestrian and vehicle flow. The calibrated case demonstrated a 48% reduction in average speed and a 5% decrease in delay time. Afandizadeh et al. (Afandizadeh et al. 2022) simulated the causes of traffic accidents in Mazandaran based on various characteristics with Aimsun. Consequently, it was shown that vehicle accidents were predominantly attributable to individual behavior rather than the acts of others. Mirzahossein et al. (Mirzahossein et al. 2024) studied the distribution of autonomous vehicles (AV) on intersection capacity using three degrees of autonomous vehicle identification, a basic traffic analysis solution, and a set of hypotheses. Finally, an improved interaction framework between smart intersections and vehicles is shown to govern intersection performance and performance at the B service level with varying AV percentages. Acuto et al. (Acuto et al. 2022) developed an approach for estimating vehicle emissions at city intersections combining smartphone data, vehicle specific power (VSP), and microscopic traffic simulation (AIMSUN). The study opened up new avenues for evaluating environmental performance in traffic management strategies and underlined the importance of massive data collection through digital communities. Granà et al. (Granà et al. 2020) estimated Passenger Vehicle Equivalents (PCEs) at roundabouts and reported that the influence of heavy trucks should be considered when evaluating the operation performance of a two-lane roundabout.

Erzincan, being a socio-economically developing city, has experienced a notable increase in both population and the number of vehicles, which has placed an additional strain on the city's traffic system. To address this issue, the study focused on evaluating seven signalized intersections along the study corridor, starting from Dortyol Intersection, known for its high traffic volume, and extending to the New Bus Terminal Intersection.

In this study, seven different scenarios were created, considering various factors such as road geometry, signal timings, and the volume of vehicles in the study corridor. The evaluation of the selected route was conducted as a whole using a mesoscopic simulation approach. This approach considers traffic flow characteristics at an intermediate level between microsimulation (individual vehicle level) and macrosimulation (network level).

The performance of intersections was evaluated using different intersection designs, including modern roundabouts, grade-separated intersections, and signalized roundabouts. Signal timings were optimized with the green wave and Webster methods. Multiple criteria were taken into account to assess the performance of these designs, including CO_2, VOC, NOx emissions, queue length, delay, travel time, stop time, speed, and construction cost. To determine the ideal

scenario among the considered designs that could help alleviate traffic congestion and enhance the overall efficiency of the transportation system in Erzincan, the TOPSIS method was employed.

2 Material and Method

Erzincan is a city in socio-economic development, with a population of 234,747 and a total area of 11,974 square meters. The focus of the study was the route between Erzincan city center and the new bus terminal intersection, which serves as the study corridor. This corridor spans approximately 4150 m in length and is known to have high traffic flow within the city, as depicted in Fig. 1. Along the study corridor, there are several intersections of significance. These intersections include Dortyol, Merplaza, Old Bus Terminal, Terzibaba, Old Police Academy, Tedas, and New Bus Terminal, as illustrated in Fig. 2. These intersections played a critical role in managing traffic along the study corridor and were a key focus of the study.

The study observed significant traffic congestion at the intersections during peak hours. This congestion indicated the presence of traffic jams and highlighted the challenges commuters face in navigating through these intersections. Moreover, the urban public transport routes also conflict at least one of these intersections. Public transport routes add further complexity to the traffic dynamics in these areas, as they contribute to the overall traffic volume.

2.1 Data Collection

Various preliminary surveys, such as vehicle counts in the study corridor, signaling times of intersections, and travel time, were carried out in the morning, noon, and evening hours. In addition, signaling phase times were obtained from the Erzincan Municipality Signalization Department. The traffic composition consists of private cars and buses.

The vehicle counts were conducted between 07:45 − 08:45, 12:00–13:00, and 16:45 − 17:45 on Mondays, Wednesdays, and Fridays. The counts differentiated between cars and buses, allowing for analyzing the traffic composition. It was observed that the period with the highest traffic density occurred on Monday from 16:45 to 17:45 based on the vehicle counts. As an example, Table 1 presents the private car counts specifically for the Dortyol intersection. It shows that 64 cars were observed coming from the west and heading south, while 66 vehicles were observed coming from the south and moving in the east direction. The traffic composition along the study corridor consisted of a total of 6,548 vehicles, comprising 6,173 cars (94.27%) and 375 buses (5.73%).



Fig. 1 Route of study



Fig. 2 Intersections at the study corridor

Table 1 Dortyol intersection private car counts

Orientations	South	East	North	West
West	64	462	243	31
South	8	66	229	123
East	170	28	52	478
North	313	186	43	78

2.2 Traffic Simulation and Calibration

The current situation can be modeled with simulation software using the parameters such as vehicle numbers, signal timing, and road geometry (Mishra et al. 2023). Researchers can simulate different scenarios and evaluate the impact on the traffic system (Bachechi et al. 2022). Generated data such as queue length, travel time, and other performance metrics give valuable information on improving traffic flow, reducing congestion, and the behavior of the traffic system under different scenarios (Forouzandeh et al. 2022).

The speed of a vehicle is assigned according to the speed-density graph while the vehicle passes through an intersection in mesoscopic simulation. Consequently, this approach reduces the simulation duration by applying the time taken for the vehicles to reach the end of the road in a simulation step (Alghamdi et al. 2022).

The study utilized the AIMSUN mesoscopic simulation program to model the current situation by inputting

Table 2 Dortyol GEH analysis

	West-East		South-North		East-West		North-South		Total
	Car	Bus	Car	Bus	Car	Bus	Car	Bus	
Observed value	800	75	426	54	728	76	620	61	2807
Simulation value	779	68	424	47	797	88	628	63	2894
GEH value	0.75	0.83	0.10	0.99	2.50	1.33	0.32	0.25	1.63
Criteria < 5	YES	YES	YES	YES	YES	YES	YES	YES	YES

Table 3 Scenarios

Intersections	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
Dortyol	Current Status	Roundabout	Current Status	Roundabout	Green Wave	Roundabout	Roundabout
Merplaza	Current Status	Webster	Webster	Current Status	Green Wave	Webster	Webster
Old Bus Terminal	Current Status	Current Status	Roundabout	Roundabout	Green Wave	Current Status	Current Status
Terzibaba	Current Status	Current Status	Signalized	Current Status	Green Wave	Grade separated	Current Status
Old Police Academy	Current Status	Signalized	Current Status	Signalized	Green Wave	Current Status	Current Status
Tedas	Current Status	Webster	Roundabout	Webster	Green Wave	Webster	Roundabout
New Bus Terminal	Current Status	Current Status	Current Status	Current Status	Green Wave	Current Status	Signalized

the collected data. Calibration of the model to characterize real-world circumstances accurately is essential when using the simulation software. This calibration process involves adjusting the default parameter values, such as flow or travel time until the error between the simulated and actual measurements is within an acceptable threshold (Siddharth and Ramadurai 2013). However, it is worth noting that there are currently no universally accepted standards in traffic engineering to determine that a model is adequately validated or calibrated (Hellinga 1998). As a result, different calibration methods, including the GEH (Geoffrey E. Havers) formula and relative error (Acuto et al. 2022; Granà et al. 2020; Mishra et al. 2023), are employed. These methods help assess the level of agreement between the simulated results and the actual data.

GEH analysis is commonly used in traffic engineering to determine if a model is adequately validated and calibrated (Ali et al. 2023; Tang et al. 2022). The GEH value should ideally range between 0 and 5 or 5–10 (Jeihani et al. 2015). The GEH value should ideally range between 0 and 5 or 5–10, with 80–85% of values falling below 5. Values between five and ten may require further examination, while values above ten are considered unacceptable (Feldman 2012). Traffic volumes counted concerning to the routes were considered calibration parameters in this study. GEH analysis performed with the simulation values is given in Table 2..

It was observed that the simulation model accurately represented the current situation after the calibration process. Using this model, parameters such as travel time, delay, fuel consumption, queue length, and emission values were obtained for 6 different scenarios, as shown in Table 3. Modern roundabouts were implemented at intersections with sufficient physical characteristics, while a grade separated intersection was applied to the Terzibaba intersection, which had adequate physical features but high traffic density. At intersections that were not suitable for the construction of modern roundabouts or grade-separated intersections, signal optimization was performed using the Webster method. The redesigned roundabout for the Old Bus Terminal Intersection can be seen in Fig. 3. The grade-separated redesign for the Terzibaba Intersection is depicted in Fig. 4. The signalized redesign for the New Bus Terminal Intersection is illustrated in Fig. 5. Each simulation was repeated 20 times, and the average values were considered as the relevant parameter values. The solutions for the 6 alternatives were then compared to the current situation to evaluate their performance.

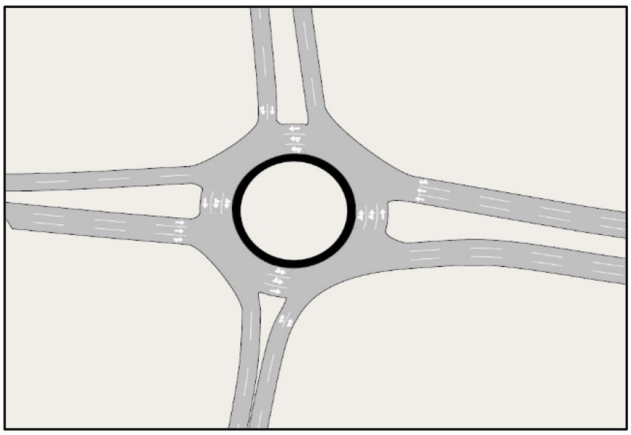


Fig. 3 Old Bus Terminal Intersection roundabout redesign

2.3 Webster Method

The Webster method, proposed by a traffic scientist (Webster 1958, 1966), is used to determine the durations of green lights at signalized intersections (Adeleke et al. 2023; Kim et al. 2023). This method considers the traffic volume on

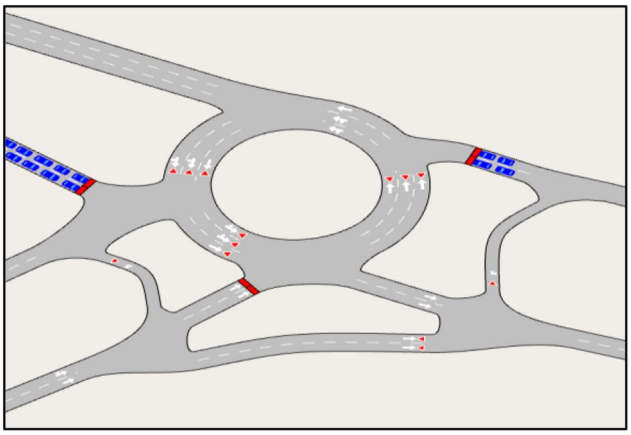


Fig. 4 New Bus Terminal Intersection signalized redesign

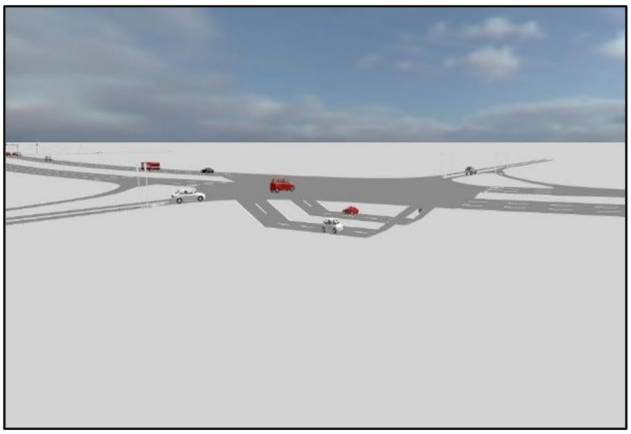


Fig. 5 Terzibaba Intersection grade separated redesign

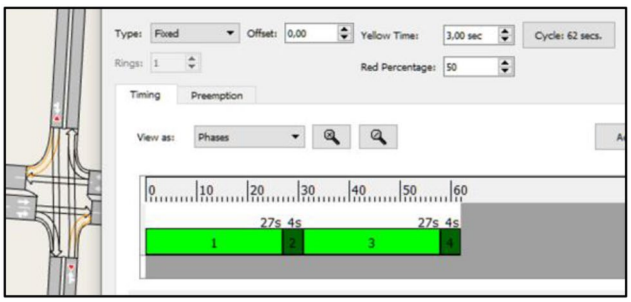


Fig. 6 Merplaza optimization times generated by Webster method

approach arms and the maximum proportion of vehicles passing through the stop point within a specified green light time (Savaş 2019). In this study, the intersections at Merplaza and Tedas were specifically optimized using this method.

For the Tedas intersection, a signal timing plan was developed with a total cycle length of 72 s. The main road was given a green light duration of 34 s, while the side road was given 30 s. The yellow light and protection red light durations were set at 3 s and 1 s, respectively.

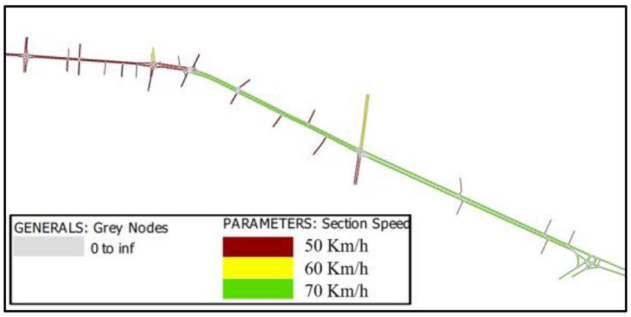


Fig. 7 Study corridor speed limits

For the Merplaza intersection, a signal timing plan was created with a total cycle length of 62 s. All directions at the intersection were allocated a green light duration of 27 s. The yellow light and protection red light durations were set at 3 s and 1 s, respectively.

The signal optimization results obtained through the Webster method for the Merplaza intersection can be seen in Fig. 6.

2.4 Green Wave

Intelligent transportation systems utilize various methods to address traffic issues. One of these methods is the implementation of a green wave system at a series of signalized intersections along a roadway (Reyad and Sayed 2023). The aim of the green wave system is to enable vehicles traveling at a determined speed on the designated main road to proceed without encountering a red light (Zhao et al. 2023). The number of vehicles traveling west to east on the study corridor was higher than those traveling from east to west. Therefore, the green wave application was implemented in the west-east direction. The signal timings at the signalized intersections were optimized with Webster method, and the performance evaluation was conducted using the AIMSUN simulation program. The speed limits along the study corridor can be seen in Fig. 7, indicating the designated speeds for a smooth progression through the green wave system.

In the study, the period times of the intersections were set to 74 s. The green light durations and offset times for each intersection were adjusted as follows:

- Dortyol intersection: Green light duration of 27 s, with no offset.
- Merplaza intersection: Green light duration of 32 s, with an offset of 27 s.
- Old Bus Terminal intersection: Green light duration of 36 s, with an offset of 61.92 s.
- Terzibaba intersection: Green light duration of 25 s, with an offset of 5.03 s.

Table 4 Desicion table

Scenarios	CO_2 (g)	VOC (g)	NOx (g)	Queue Length (vehicle)	Stop Time (sec)	Delay (sec)	Travel Time (sec)	Speed (km/h)	Cost ($)
Scenario 1	1,580,502	2,615	3,770	70	58.43	73.49	135.25	33.93	-
Scenario 2	1,443,566	2,327	3,376	50	37.89	50.86	112.24	38.14	35,000
Scenario 3	1,497,878	2,287	3,522	46	44.61	58.48	120.22	37.58	60,000
Scenario 4	1,420,664	2,258	3,291	46	36.00	48.04	109.42	39.17	60,000
Scenario 5	1,557,749	2,435	3,746	57	53.56	68.27	129.97	35.07	-
Scenario 6	1,409,026	2,215	3,255	43	33.28	45.63	107.06	39.56	1,700,000
Scenario 7	1,444,671	2,331	3,364	48	37.48	50.29	111.59	39.16	60,000

Table 5 Standard decision matrix

Scenarios	CO_2	VOC	NOx	Queue Length	Stop Time	Delay	Travel Time	Speed	Cost
Scenario 1	0.4035	0.4195	0.4094	0.5082	0.5026	0.4847	0.4318	0.3413	-
Scenario 2	0.3685	0.3734	0.3667	0.3614	0.3259	0.3355	0.3583	0.3837	0.0205
Scenario 3	0.3824	0.3669	0.3825	0.3344	0.3837	0.3857	0.3838	0.3781	0.0352
Scenario 4	0.3627	0.3622	0.3574	0.3315	0.3096	0.3169	0.3493	0.3941	0.0352
Scenario 5	0.3977	0.3906	0.4068	0.4144	0.4607	0.4503	0.4149	0.3528	-
Scenario 6	0.3597	0.3553	0.3534	0.3117	0.2863	0.3010	0.3418	0.3980	0.9979
Scenario 7	0.3688	0.3740	0.3654	0.3472	0.3224	0.3317	0.3562	0.3940	0.0352

- Old Police Academy intersection: Green light duration of 27 s, with an offset of 24.14 s.
- Tedas intersection: Green light duration of 33 s, with an offset of 71.14 s.
- New Bus Terminal intersection: Green light duration of 29 s, with an offset of 11.70 s.

These signal timings were implemented to create a coordinated traffic flow along the studied corridor and optimize the intersection operations.

2.5 TOPSIS Method

TOPSIS (Hwang et al. 1981) is one of the multiple-criteria decision methods used widely in several fields such as engineering, business, and marketing Advantages, such as straightforward interpretation and comprehensibility of the results, made it preferred in different fields (Çilingir 2019). TOPSIS evaluates alternatives based on the predetermined criteria and determines their similarity to the ideal solution (Özden et al. 2023; Salih et al. 2019).

The TOPSIS method typically involves six stages. In the first stage, the decision matrix was created using the simulation results obtained from each scenario, as shown in Table 4.

Next, the squares of each cell in the column were added, and the square root of the total was calculated. Finally, each cell in the column was divided by this total square root value, creating a standard decision matrix as given in Table 5. This standardization step provided the criteria to be treated equally for comparisons.

In the third stage, the weights of the evaluation criteria were determined. It should be noted that this stage is subjective, and decision-makers may have different opinions on the importance of each criterion (Ertikin 2019). For this study, the following evaluation criteria and their respective weights were determined:

- Cost: %15.
- Delay: %13.
- Stop time: %12.
- CO_2, VOC, and NOx emissions, queue length, speed, and travel time: %10 each.

In the fourth stage, In the fourth stage, the positive and negative ideal points representing each criterion's best and worst values were calculated. In the fifth stage, the separation measure was applied to find each alternative's rating distance from the positive and negative ideal solutions. This measure determines how far each alternative is from the ideal solutions, considering both positive and negative aspects.

Finally, in the sixth stage, the overall preference score for each alternative was calculated. This value between 0 and 1 points out the proximity of the alternative to the ideal solution. A score that is closer to 1 points out a higher preference, while a score that is closer to 0 points out a lower preference. The alternatives were ranked based on these scores and the alternative having the highest proximity coefficient was chosen as the best alternative.

3 Results and Discussion

3.1 Simulation Application

According to the results obtained from the AIMSUN software for each scenario, the following improvements were observed:

Delay time decreased by %31 for Scenario 2, %20 for Scenario 3, %35 for Scenario 4, %7 for Scenario 5, %38 for Scenario 6, and %32 for Scenario 7, as given in Fig. 8.

Travel time decreased by %17 for Scenario 2, %11 for Scenario 3, %19 for Scenario 4, %4 for Scenario 5, %21 for Scenario 6, and %17 for Scenario 7.

Stop time decreased by %35 for Scenario 2, %24 for Scenario 3, %38 for Scenario 4, %8 for Scenario 5, %43 for Scenario 6, and %36 for Scenario 7.

Speed improvements were achieved by %12 for Scenario 2, %11 for Scenario 3, %15 for Scenario 4, %3 for Scenario 5, %17 for Scenario 6, and % 15 for Scenario 7.

CO_2 decreased by %9 for Scenario 2, %5 for Scenario 3, %10 for Scenario 4, %1 for Scenario 5, %11 for Scenario 6, and %9 for Scenario 7, as given in Fig. 9.

VOC decreased by %11 for Scenario 2, %13 for Scenario 3, %14 for Scenario 4, %7 for Scenario 5, %15 for Scenario 6, and %11 for Scenario 7.

NOx decreased by %10 for Scenario 2, %7 for Scenario 3, %13 for Scenario 4, %1 for Scenario 5, %14 for Scenario 6, and %11 for Scenario 7.

The queue length decreased by %29 for Scenario 2, %34 for Scenario 3, %35 for Scenario 4, %18 for Scenario 5, %39 for Scenario 6, and %32 for Scenario 7.

3.2 TOPSIS Evaluation

The data obtained from the analysis with the AIMSUN simulation program were compared by considering the preselected criteria. Weights for each of these criteria were determined subjectively. Since the determination of the weights of the criteria is subjective, there may be differences between decision-makers (Demireli 2010).

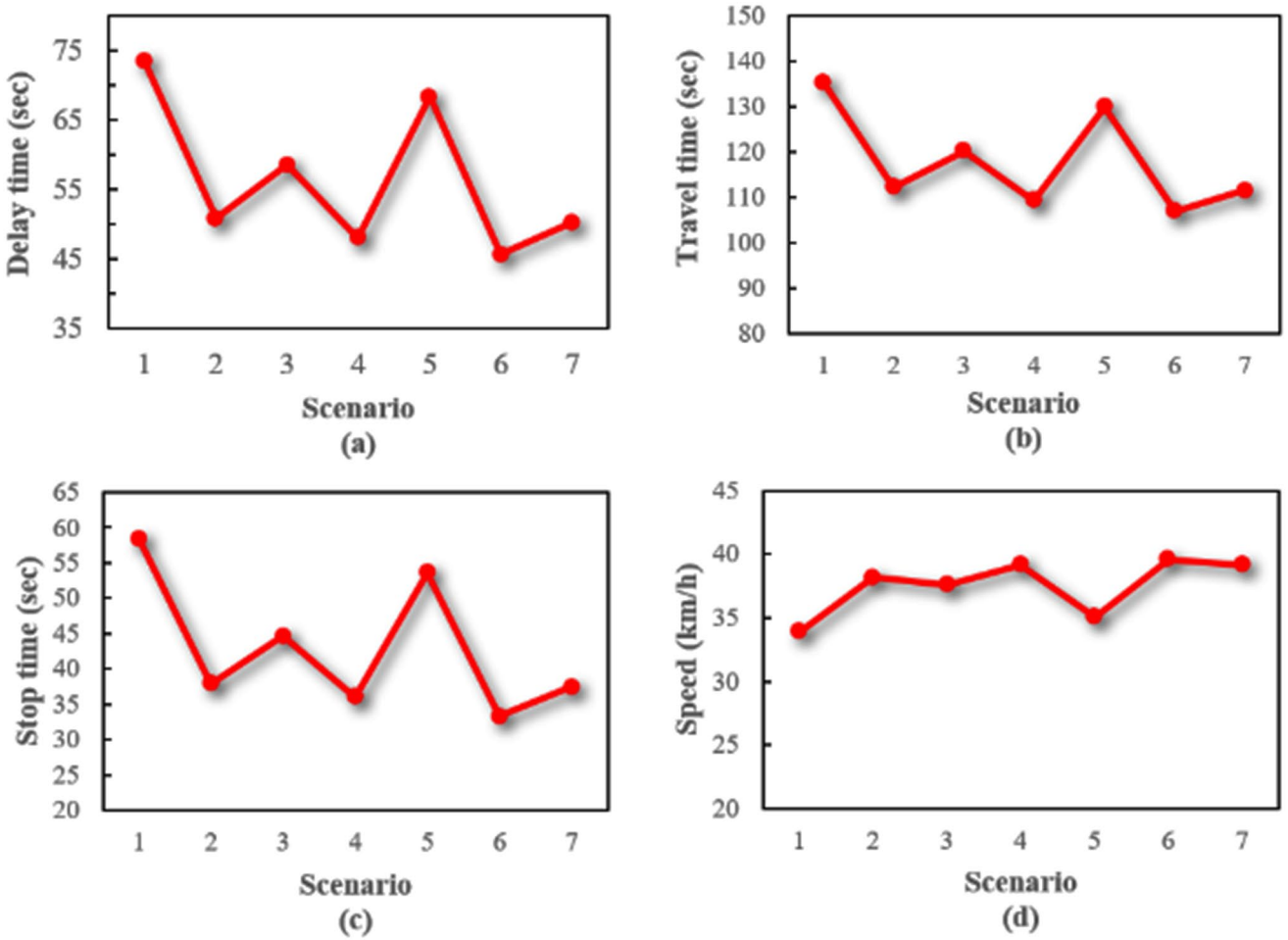


Fig. 8 Delay time, travel time, stop time, and speed comparison

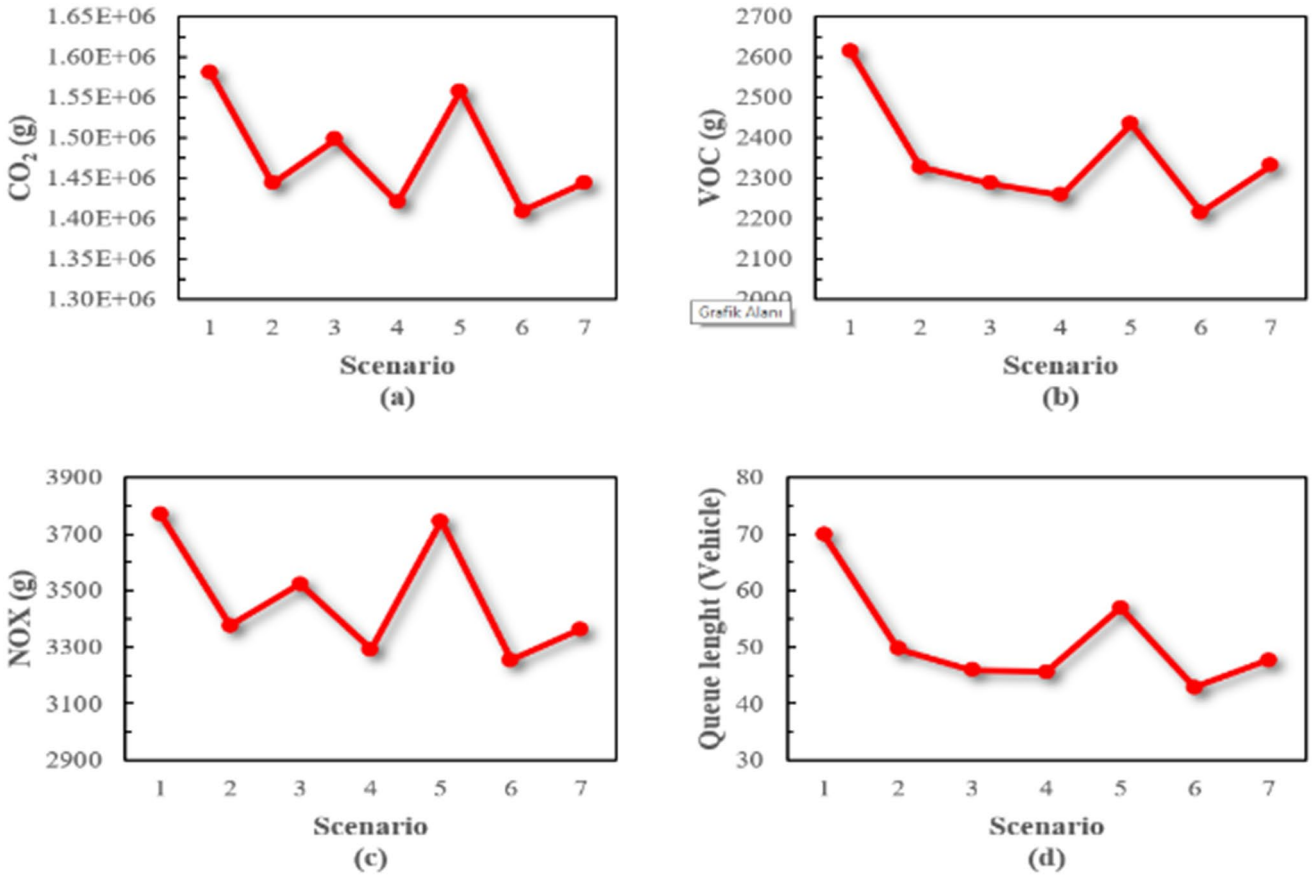


Fig. 9 CO_2, VOC, NOx, and queue length comparison

Table 6 Proximity to the ideal solution

Scenarios	C	Rank
Scenario 1	0.7775	6
Scenario 2	0.9415	3
Scenario 3	0.8903	4
Scenario 4	0.9569	1
Scenario 5	0.8225	5
Scenario 6	0.2225	7
Scenario 7	0.9422	2

The proximity to the ideal solution was assessed for each scenario separately. Scenario 4 was identified as the ideal scenario based on the TOPSIS method, and the proximities to the ideal solution are presented in Table 6.

3.3 Comparison of Results from the Ideal Scenario With Related Studies

The comparison of the optimization percentage achieved in Scenario 4 with the optimization percentages reported in other studies is presented in Table 7. Erol (Erol 2018) concluded that modern roundabouts experienced a greater increase in average delay compared to signalized intersections as demand increased across three distinct scenarios for both intersection types. In the study performed by Savaş (Savaş 2019), the average speed increased by 23%. Similarly, the study conducted by Alemdar et al. (Alemdar et al. 2021) focused on three intersections in Istanbul. Although

Table 7 Comparison of scenario 4 results with previous research

Research	CO_2 (%)	VOC (%)	NOx (%)	Queue Length (%)	Stop Time (%)	Delay (%)	Travel Time (%)	Speed (%)
Scenario 4	10	14	13	35	38	35	19	15
Erol (2018)						-57		-25
Demiriz et al. (2021)	13		11	48		47	23	13
Savaş (2019)						32		23
Forouzandeh et al. (2022)	41		8			33		
Alemdar et al. (2021)				79	73	45	25	
Afandizadeh et al. (2022)						20	30	
Garmei et al. (2019)					-6	6		-48

the study was limited to three intersections, it included significant vehicle diversity. In the study conducted by Garmei et al. (Garmei and Kashi 2019), the average speed decreased by 48% because the intersections were designed according to pedestrian dynamics. All metrics listed in Table 7 were utilized in this study, and previous studies considered some of these metrics. This study demonstrated successful performance in selecting ideal intersection designs through corridor-based planning using the TOPSIS methodology, a multi-criteria decision-making approach.

4 Conclusion

This study aimed to mitigate travel delays and environmental pollution in the Erzincan city center due to the growing number of vehicles. Seven scenarios were developed using AIMSUN to analyze the geometry of intersections along the study corridor, signal timings, and traffic volume. CO_2, VOC, and NO_x emissions, queue length, delay, travel time, stop time, and speed parameters were evaluated using the TOPSIS multiple criteria decision method, which also incorporated construction costs. The most suitable scenario was identified based on this analysis. The findings demonstrated that integrating simulation and decision-making methodologies is a practical approach to designing comfortable, safe, and sustainable road networks by optimizing traffic flow and emissions. Furthermore, this study emphasized the crucial need to assess the physical suitability of intersections and to evaluate the costs associated with implementing design changes. The results obtained are given below in comparison with the current situation.

Among the alternative scenarios, Scenario 6 achieved the lowest CO_2, VOC, and NOx emissions, with reductions of 11%, 15%, and 14%, respectively. On the other hand, Scenario 5 had the highest emissions but still managed to reduce them by 1%, 7%, and 0%, respectively. Scenario 6 also had the lowest queue length, reducing it by 39%, while Scenario 5 had the highest queue length but still achieved a reduction of 19%.

Regarding delay time, travel time, and stop time, Scenario 6 outperformed the other scenarios, achieving reductions of 38%, 21%, and 43%, respectively. In contrast, Scenario 5 had the highest values for these parameters but still achieved reductions of 7%, 4%, and 8%, respectively. Furthermore, Scenario 6 had the highest speed and saw a 17% increase, while Scenario 5 had the lowest speed but still experienced a 3% increase.

Based on the evaluation criteria, particularly considering construction costs, Scenario 4 was selected as the best feasible solution according to the TOPSIS method.

Declarations

Conflict of interest The authors declare no conflicts of interest.

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