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Research Article

Investigation of the Impact of Intersection Designs, Signalization, and Directions of Intersection Arms on Microscopic Networks: The Case of Erzurum Province

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ABSTRACT

Transportation has an important connection in many aspects such as economic growth, trade, tourism and social interaction. Today, the demand for transportation services is increasing with the rapid socio-economic development. This increase brings with it various traffic problems. Effective intersection design in preventing congestion, delays and accidents is of great importance in terms of ensuring traffic safety and sustainability. In this study, Gürcükapı Intersection and Taşhan Intersection were remodeled with Aimsun software in order to reduce the density at the intersections in Erzurum province and to meet traffic needs. Signalization was added to the modeled intersections, the directions of the intersection arms were changed and four alternative scenarios were created with these changes using current scenario. A total of five scenarios, including the current scenario and the developed alternatives, were evaluated and compared based on travel time, delay time, waiting time, speed, queuing, instant CO_2, NO_x, PM (Particulate Matter) and VOC (Volatile Organic Compounds) values. As a result of the comparison, the scenario in which the current intersection arm direction and Gürcükapı and Taşhan intersections are modernized and there is no signaling system was determined as the most effective scenario.

1. Introduction

The expansion and alteration of urban areas result in an increase in the human population and intensified economic activities. This situation increases the variety of urban activities while concurrently improving citizens' mobility and transportation needs. The unchecked and rapid proliferation of vehicles has led to inadequate lanes for the surplus cars, prompting the conversion of at-grade intersections into multi-level intersections, and resulting in the transformation of urban roads into ring roads and ultimately into fully controlled access highways [1]. In modern culture, speed has become an essential requirement, and goals have gained importance due to time constraints. In this case, individuals' efforts to achieve safety, comfort, and convenience shape their lifestyles [2].

Intersections are the most conspicuous sites of traffic congestion on highways and promote safe traffic flow when constructed appropriately. Nonetheless, in instances of insufficient design, they pose the possibility of precipitating accidents [3]. Intersection design, a fundamental component of urban planning, encompasses technical analyses to guarantee the safety of road users and promote seamless transit between converging roadways. An effective intersection design must decrease vehicular wait times, alleviate traffic congestion, and ensure a secure environment for pedestrians.

The development, implementation, and optimization of traffic control and management strategies are critical to ensure that intersections operate efficiently over time [4]. This process requires updating the geometric design to

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respond to constantly changing needs. However, there are difficulties in determining ideal lane widths. Although wide lanes are advantageous in terms of comfort of use and safety, they are generally not preferred due to reasons such as project costs and narrowing of the surrounding area [5]. This situation requires careful planning and evaluation to ensure balance in intersection design. Estimating emissions about environmental implications is essential for efficient traffic management and intersection design [6].

The design of intersections must consider the geographical, demographic, economic, and social attributes of the region. The distinct dynamics of each region are the paramount factors that influence the efficacy of intersecting configurations [7]. Traffic simulation programs significantly enhance the efficient planning of transportation networks and the reduction of safety issues. These algorithms provide robust instruments for evaluating dynamic transportation issues that cannot be implemented under real-world circumstances [8]. The simulated environment allows for the observation of results minutes, hours, days, and even weeks prior to those obtained from the identical experiment conducted in the real world [9]. In the initial phase of all simulation programs, the problems are defined, and the corresponding solutions are included into the program. The validity-consistency test involves evaluating the correlation between the simulated designs and the current conditions. In the event that the test results are deemed unsuitable, the simulations will be re-executed [10].

When examining studies on traffic, it is evident that various works focus on human behavior [11-12] and [13-15] the geometric and systematic arrangements within traffic networks. A review of the literature reveals various studies related to traffic simulation. Çakıcı and Murat [13] proposed a computational approach to determine the optimal signal timing and phase plan in the design of signalized roundabouts. In their study, they conducted performance analyses based on delay criteria by considering different intersection types and phase plans. The research findings suggest that in scenarios with high left-turn ratios and increased numbers of signal phases, alternative intersection designs may be more suitable than signalized roundabouts.

Bayata et al. [14] selected Erzincanpark as their study area to examine the significance of intersection coordination, traffic flow, and phase adjustments. They analyzed traffic volumes, signal optimization, travel time, queue length, delay, CO_2, NO_x, VOC emissions, and fuel consumption at intersections along Halitpaşa Street. The study results indicate that the Yıldız and Nedim Muratoğlu intersections should be redesigned as modern roundabouts to achieve optimal performance. Demiriz et al. [15] analyzed the increasing transportation demands and traffic congestion in Erzincan, where main arteries and intersections were found to be insufficient. Using the Aimsun program, simulations were conducted for the current situation and four alternative scenarios, with delay time and travel time serving as key design criteria, assessed through the Analytic Hierarchy Process (AHP). The study found reductions of up to 23% in travel time, 47% in delays, 48% in queue lengths, 11% in NO_x emissions, and 13% in CO_2 emissions, along with an increase of up to 30% in average speed.

Nguyen et al. [16] highlighted the impact of individual traffic behavior on environmental degradation and underscored the importance of innovation in sustainable mobility. The study demonstrated that agent-based models are particularly effective in addressing three key areas—resource usage, digital connectivity, and emerging forms of mobility—due to their ability to model heterogeneous individual behaviors. Furthermore, the authors evaluated existing simulators, examining both their modeling capabilities and identifying critical functional limitations. Çelikoglu and Dell'Orco [17] proposed a mesoscopic simulation methodology that incorporates vehicle acceleration and deceleration to address the complexities of flow propagation in transportation systems. The model is particularly effective in improving the accuracy of speed calculations on long road segments, such as highways. Simulation results indicate that the model realistically captures exit dynamics and is computationally efficient.

Mecheva et al. [18] present a methodology for integrating driver behaviors into traffic simulations by testing various car-following models and routing algorithms. Based on over 7,000 simulations using traffic data from Plovdiv, the study identifies the Contraction Hierarchies routing algorithm and the Krauss car-following model as providing the best overall performance and compatibility. In the study of Guo et al. [19], traffic simulation models were calibrated using extreme value theory, achieving alignment between simulated conflicts and field data. This approach enables more accurate crash predictions.

Qin et al. [20] developed a genetic algorithm-based calibration model in VISSIM for a signalized intersection in Beijing. By calibrating four driver behavior parameters, they reduced queue length error from 31.3% to 9.8% and travel time error from 15.2% to 7.3%, successfully replicating real-world traffic conditions. Zhang et al. [21] developed an efficient calibration framework for large-scale traffic simulators, based on meta-model simulation-based optimization algorithms. The meta-model incorporates analytical, structural, and problem-specific knowledge. It was applied to address a calibration problem for the Berlin network, which consists of 11,300 nodes. The proposed approach significantly enhances the computational efficiency of the calibration algorithm, achieving over 80% average reduction in simulation runtime. The results demonstrate the scalability of the approach and its suitability for calibrating large-scale, computationally intensive network simulators.

Although traffic congestion is often attributed to traffic signals, Moreno et al. [12] argue that human behavior also plays a significant role. To analyze the impact of human factors and their responses to the environment on traffic performance during waiting times, they developed an agent-based simulation that models both autonomous and social behaviors of road users. The results indicate that age is the most influential factor affecting individuals' behavior on the road. Xu et al. [22] present a system that operates using real-time data to deliver flexible signal control with the goal of reducing traffic congestion. The system offers three different control modes: fixed-time, multi-time, and adaptive. Supported by the SUMO simulation platform, the software enables smarter and more efficient traffic management.

Fabianova et al. [23] demonstrate how VISSIM software can be used to alleviate congestion at a signal-controlled intersection. To increase the throughput of a selected high-traffic intersection, two different improvement models were developed and simulated. The effectiveness of these models was evaluated based on vehicle queue lengths, a key indicator directly linked to traffic congestion. Both models significantly reduced queue lengths, particularly in the most congested directions. The first model achieved a 75% reduction in average queue length, while the second model improved the flow of right-turning vehicles and further reduced queues in other directions. Bindzar et al. [24] investigate the optimization of signal plans at urban intersections using ExtendSim8, a general-purpose simulation software, with the aim of alleviating traffic congestion. Based on real-world traffic data and observations, their modeling results show that this software can be an effective tool for urban traffic management.

Stevanovic et al. [25] demonstrate that traffic signal timings can be optimized using a three-dimensional Pareto analysis that considers mobility, safety, and environmental impacts. The proposed approach offers more balanced traffic management solutions by integrating both traditional methods and connected vehicle technologies. Cao et al. [26] aim to improve traffic management by using intelligent traffic light systems and simulations for continuous linear multiple intersections. Simulations conducted with Python and Vissim software provide an effective method for real-time adjustment of traffic signals at intersections, helping to reduce traffic congestion.

Baş et al. [27] simulated different intersection types using Aimsun software to reduce traffic congestion at the Tebrizkapı Intersection in Erzurum. They proposed the designs of a Modern Roundabout and a Grade-Separated Intersection as alternatives to the existing intersection type. Simulation results indicated that, despite its high cost, the Modern Roundabout design was the

most optimal solution. Bayata et al. [28] conducted a traffic simulation of seven signalized intersections in the city center of Erzincan and evaluated improvements across various parameters. Using the TOPSIS method, the ideal scenario was determined, resulting in significant improvements in factors such as CO_2 emissions, delay time, VOC and NO_x emissions, and queue length.

In the study by Demiriz et al. [29], the intersection near Erzincan Mengücek Gazi Education and Research Hospital—a major hub in the city with a capacity of 500 beds—was analyzed. During peak periods, up to 676 vehicles use roadside parking at this location. The study identified user expectations and needs, and simulated the intersection using the Microscopic Simulation Method with the Aimsun program. The most suitable intersection design was determined based on factors such as delay, travel time, stop duration, and overall feasibility. Xu et al. [30] adopted a data-driven approach to generate traffic behaviors from real-world driving logs. The method utilizes a two-level hierarchy between high-level intent inference and low-level driving behavior imitation to achieve high sample efficiency and behavior diversity, while also incorporating a planning module to ensure stable long-term behaviors. The method has been empirically validated with scenarios from two large-scale driving datasets, demonstrating balanced traffic simulation performance in terms of realism, diversity, and long-term stability.

Aimsun and other microsimulation tools accurately model traffic flow through the analysis of interactions among individual vehicles [31]. Urban planners and traffic engineers rely on simulation programs to increase the efficiency of transportation networks [32]. Aimsun was originally developed as a simulation tool for microscopic traffic studies in urban and extra-urban contexts, but it has since evolved. When the Aimsun software was first designed, intersection measurements were modeled in the AutoCAD program by taking points in the field and the existing values were used in the measurements [33].

Rodríguez et al. [34] used Aimsun software to simulate a new parking model with two sub-models: parking lot selection and search. This model, which accounted for sidewalk traffic, was implemented in microsimulation traffic software. Sub-model parameters were estimated using data from Santander, Spain, and a user preference survey. For policy testing, the model was executed in Aimsun via a Python 3.7 API. Yalçınlı et al. [35] report that it now generates simulation models at both mesoscopic and macroscopic scales. The microsimulation model's usefulness in depicting emissions is dependent on its ability to simulate vehicle dynamics and temporal evolution. The simulation phase faithfully duplicates each vehicle's dynamic behavior using several internal behavior models [36].

This study proposes to improve intersection design to address the growing transportation needs of Erzurum and alleviate traffic congestion. To improve traffic flow at the Erzurum Gürcükapı and Taşhan Intersections, we assessed the current conditions and conducted renovation studies. In this methodology, we developed four unique scenarios by rearranging the intersecting arms and integrating additional signaling systems. The research examined variables including travel time, delay time, waiting time, speed, queuing, and environmental effects—specifically instantaneous emissions of CO_2, NO_x, PM (Particulate Matter), and VOCs (Volatile Organic Compounds)—across five separate scenarios. To calculate the emission values, the emission model of Panis et al. [37] was used in Aimsun for the simulation scenarios created in this study. The aim was to improve sustainable and secure traffic flow. This document underscores the necessity for enhancements in the city's transportation infrastructure, particularly through the optimization of intersection efficiency.

In the study, different scenarios were analyzed using the Aimsun program and as a result of these analyzes, evaluations were made on parameters such as travel time, delay time, waiting time, speed, queuing, instant CO_2, NO_x, PM and VOC. In addition, the effects of geometric arrangements and direction changes on the intersection were examined and travel time,

delay time, queue lengths and waiting time were taken into account as criteria measuring traffic performance. As a result, it was determined which design and direction arrangements were more suitable and future traffic density changes were analyzed using count data. In this way, evaluations were made on the effective usability of the projects in the coming years.

1. Materials and Methods

1.1. Study area

The research area includes the Gürcükapı and Taşhan intersections in Erzurum province, as well as surrounding streets Taşhan and Habib Baba Street. Figure 1 depicts satellite images of the research area.

Figure 1. Satellite image of study area

Two alternative recommendations were chosen from a list of various choices, and 40 questionnaires were issued to see how changing the directions of Taşhan Street and Habib Baba Street might affect traffic flow for local businesses. A 3D model of the selected alternative projects, together with the current geometric configuration, was developed using SketchUp software. Data on intersection numbers and signal durations were obtained from the Transportation Planning Branch Directorate of Erzurum Metropolitan Municipality. Utilizing Aimsun simulation software, comparisons were conducted across three scenarios: the two alternative designs and the existing intersection arrangement.

Traffic counts were performed at two intersections at peak hours on weekdays (morning, noon, and evening) and weekends (morning, noon, and evening) for a duration of one hour. The counts were derived from the vehicle types identified in the camera clip. Figures 2-5 present satellite imagery of the intersections along with the corresponding intersection count data.

Figure 2. Satellite image of Gürcükapı Intersection

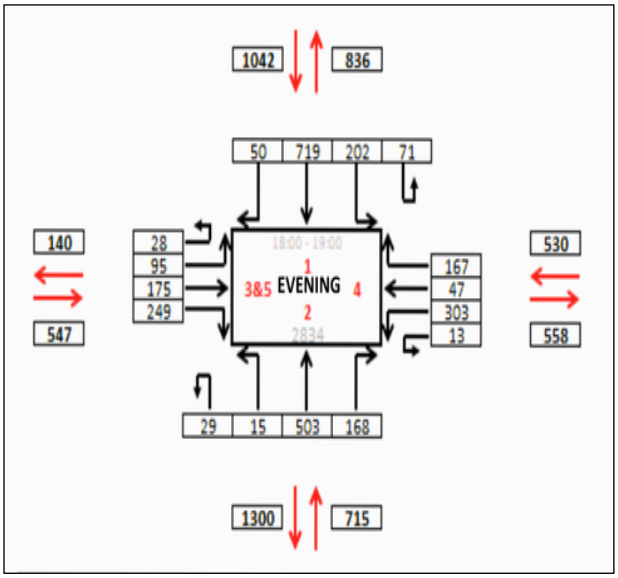

Figure 3. Vehicle Count Matrix of Gürcükapı Intersection (Evening 18:00-19:00)

Figure 4. Satellite image of Taşhan Intersection

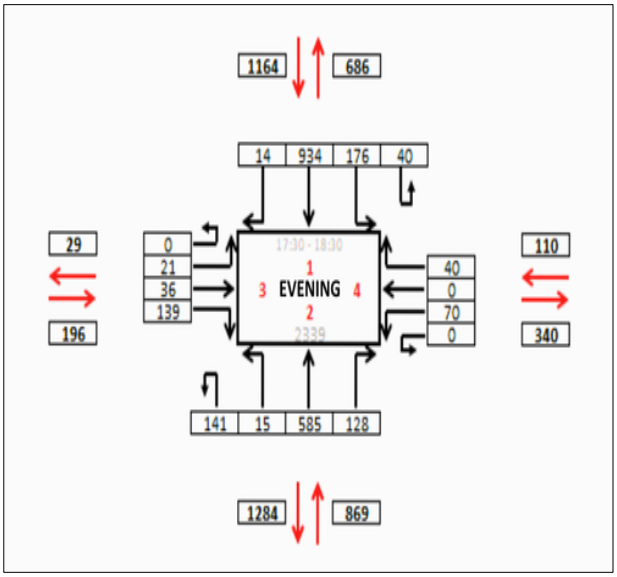

Figure 5. Vehicle Count Matrix of Taşhan Intersection (Evening 18:00-19:00)

1.2. Survey study

At the outset of the study, a structured survey was conducted targeting tradesmen operating within the Gürcükapı and Taşhan commercial districts. A total of 40 shop owners participated in the research. The findings showed a nearly even split: 49% of respondents favored changes—such as renovations, modernization, or improved business conditions—while 51% preferred to keep things as they are, indicating either satisfaction with the current setup or concerns about potential disruptions. Table 1 presents the questions from the survey conducted on these tradesmen.

1.3. Modeling of existing and alternative circumstances

When picking the type of intersection, it's important to think about things like safety, average delay, suitability for the land, and cost, and then choose the type that works best in these situations [38]. To better understand the performance of different intersection types, a comprehensive evaluation was conducted on ten distinct projects. This analysis focused on assessing the effectiveness of the selected intersection models by examining geometric arrangements and directional studies. These evaluations provide insight into how various intersection designs impact traffic flow, congestion, and overall accessibility. Figure 6-7 presents the existing and alternative situational models of the Gürcükapı and Taşhan intersections. Table 2 contains information about the current situation and scenarios.

Figure 6. Current state of Gürcükapı and Taşhan intersections

Figure 7. Alternative modeling of Gürcükapı and Taşhan intersections

Table 1. Gürcükapı-Ayaz Paşa direction survey study for commercial enterprise

	EXPLANATION	YES	NO	IF YOUR ANSWER NO, WHY?
1	Are you satisfied with the current route from Gürcükapı Street to Kongre Street?			
2	Are you satisfied with the current route from Taşhan instersection to Ayaz Paşa?			
3	Do you think it is appropriate to use the one-way road from Kafaflar Street to Ayaz Paşa Street and use the Taşhan instersection as a two-way connection?			
4	Do you think it is healthy for the Ayaz Paşa Street-Bat Pazarı – Habib Baba road intersection to be used as a two-way street in terms of traffic safety?			
5	Do you find the median opening connecting Habib Baba to Gürcükapı Street appropriate?			
6	Do you think it is necessary to return from Habib Baba to Kafaflar Street?			
7	Do you think it would be appropriate to divert the traffic coming from Habib Baba Street behind the Gürcükapı Mosque?			
8	Do you think it would be appropriate to give the route from Kongre Street to Habib Baba?			
9	Which of our project direction alternatives would you prefer?	**Alternative 1 ( )**		**Alternative 2 ( )**
Alternative 1(Current Direction) ➢ Coming from Istasyon Street, it continues in front of Guürcükapı Mosque to Kongre Street. ➢ Those coming from Habib Baba are connected to the Gürcükapı instersection from behind the Gürcükapı Mosque, without allowing those coming from Habib Baba to use the Gürcükapı instersection connection. ➢ Those coming from Gürcükapı will have a connection to Kafaflar Street, while those coming from Habib Baba and Kongre will not have a connection to Kafaflar Street. ➢ Those coming from Taşhan İnstersection will be able to go to Habib Baba by maintaining the current direction to Ayaz Paşa Street. ➢ Those coming from Ayaz Paşa will use Cedid and Eski Bat Pazarı in both directions. ➢ The Mahallebaşı direction route will continue in two directions.				
Alternative 2 (Opposite Direction of Current State) ➢ Coming from the Istatsyon Street, it continues from the front of the Gürcükapı Mosque to the Kongre Street. ➢ They will be able to go to Habib Baba from Gürcükapı Street – Kongre Street. ➢ By changing the direction of Habib Baba Route, they will be able to go to Gölbaşı via the newly opened road. ➢ A connection will be provided from Habib Baba to Ayaz Paşa in the opposite direction of the existing road. ➢ There will again be two-way transportation from Habib Baba cemetery to Mahallebaşı ➢ Those coming from Mahallebaşı and Habib Baba will be able to go from Ayaz Paşa to Menderes Street.				

Upon assessing the present circumstances, issues such as geometric irregularities at intersections, insufficient parking availability, double-row parking configurations, waste accumulation beyond designated lanes, inadequate pedestrian crossings jeopardizing safety, inappropriate spacing of existing pedestrian crossings, intersection geometry failing to adhere to roundabout specifications, turns lacking adequate storage areas, non-compliant islands, central medians not meeting established standards, complications at bus stops, directional ambiguities, and the absence of appropriate stops for articulated buses were identified.

These findings resulted in the development of project designs that integrated 10 unique directions and geometric alterations. Among the developed projects, progress was made on two alternative initiatives, considering the prevailing circumstances and minimizing damage to the geometric arrangement.

Gürcükapı Intersection: Despite the 2*2 configuration, Ayaz Paşa and Habib Baba Streets function unidirectionally due to the existing infrastructure and lane width. Vehicles entering from Ayaz Paşa Street continue to Gürcükapı Street and Kongre Street via Habib Baba Street. The project aims to decrease congestion at the Gürcükapı Intersection and plans to reorganize Habib Baba Street and Ayaz Paşa Street to create a counterclockwise ring.

When establishing one-way highways, it is essential to evaluate the origin and destination sites, intersections, land use issues, and the lengths of primary and secondary arteries [39]. One-way road implementations can be effective in cities with a systematic network configuration. Nevertheless, if the distances between roads are overly lengthy or if the road network is uneven, as observed in historic city centers, one-way systems may result in superfluous vehicular congestion and an escalation in traffic volume [40].

Table 2. Information about current status and alternative scenarios

	Geometrical Layout	Island Radius	Island	Signal Conditions	Direction Conditions
Current Status					
Gürcükapı	Currently, the lanes are used as either two-lane or single-lane configurations. The number of lanes fluctuates, leading to undefined lane spaces and the creation of double-row parking areas. The Gürückapı intersection is modeled as a roundabout, while the Taşhan intersection is modeled as a mini roundabout, with a four-node configuration.	15 m	None	The current signal system operates in 4 phases and in a storage format.	Ayaz Paşa Street flows towards Habib Baba Street, and Habib Baba Street directs traffic towards Kongre Street. A ring has been formed with a transition from Habib Baba Street to Gürcükapı Street.
Taşhan		7.75 m	4	None	
Same Direction Without Signaling					
Gürcükapı	In the design phase, the lanes have been set at 3 meters wide, with the remaining areas designated as parking pockets, and the leftover space has been allocated for sidewalks. At the Gürcü Kapı intersection, the island diameter has been increased to 30 meters. The existing Taşhan intersection with 4 nodes and the mini roundabout have been removed, and in their place, islands with a droplet shape have been designed, featuring separate entrances and exits.	30 m	None	The current signal system operates in 4 phases and in a storage format.	Same as "Current Status"
Taşhan		None	Teardrop Type Intersection	None	
Same Direction Without Signaling					
Gürcükapı	Same as "Same Direction Without Signaling"	30 m	None	The current signal system operates in 4 phases and in a storage format.	Same as "Current Status"
Taşhan		None	Teardrop Type Intersection	The signal assignment has been made to operate in 4 phases.	
Reveerse Direction With Signaling					
Gürcükapı	Same as "Same Direction Without Signaling"	30 m	None	The current signal system operates in 4 phases and in a storage format.	Gürcü Kapı Street flows towards Habib Baba Street and Kongre Street, while Habib Baba Street directs traffic towards Ayaz Paşa Street. Ayaz Paşa Street, in turn, forms a ring by directing traffic towards Cumhuriyet Street.
Taşhan		None	Teardrop Type Intersection	None	
Reverse Direction With Signaling					
Gürcükapı	Same as "Same Direction Without Signaling"	30 m	None	The current signal system operates in 4 phases and in a storage format.	Same as "Reverse Direction With Signaling"
Taşhan		None	Teardrop Type Intersection	The signal assignment has been made to operate in 4 phases.	

SketchUp is a widely used 3D modeling software, primarily employed in architecture, interior design, engineering, construction, and game design. Its compatibility with industry-standard file formats such as DWG and DXF, along with its seamless integration with other design software like AutoCAD, makes it an essential tool for professionals in various fields.

In this study, SketchUp was utilized to create a sub-database for the Aimsun program, which is used for traffic simulation and analysis. To ensure accuracy, buildings were modeled based on their real-world dimensions and appearance, providing a detailed visual representation. These models were then integrated into the program for further evaluation and project development.

Additionally, alternative intersection designs for Gürcükapı and Taşhan were modeled using SketchUp. Figures 8-9 illustrate different layout possibilities, while Figures 10-12 present signaling plans that compare the current traffic conditions with proposed alternative scenarios.

Figure 8. Alternative modeling of Gürcükapı Intersection with SketchUp

Figure 9. Alternative modeling of Taşhan Intersection with SketchUp

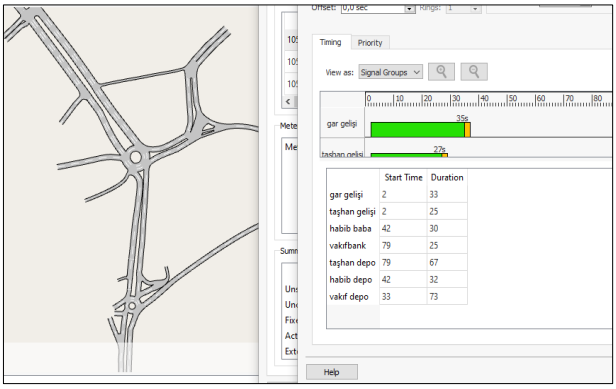

Figure 10. Current signal modelling of Gürcükapı Intersection

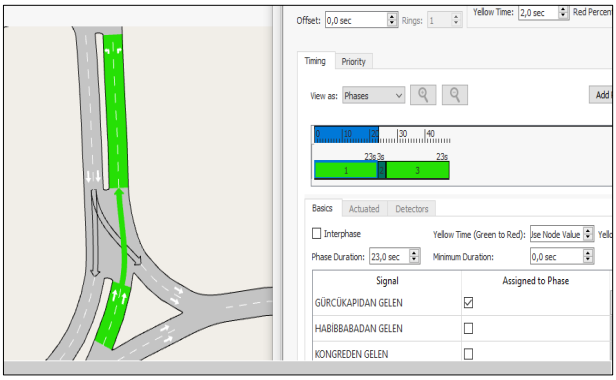

Figure 11. Signal modelling of Taşhan Intersection for alternative situations

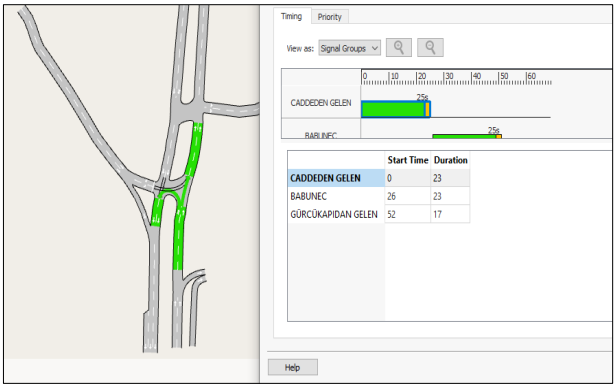

Figure 12. Signal modelling of Taşhan Intersection for alternative situations

2. Results and Discussion

The Aimsun program modeled the alternative projects as a SketchUp sub-model, arranging them according to new geometric designs. The existing intersection model, the geometrically arranged alternative project, and the geometrically arranged projects were simulated by changing the direction. The analysis values obtained later were compared in this section.

	Delay Time (sec/km)	Mean Queue (vehicle)	Speed (km/h)	Waiting Time (sec/km)	Travel Time (sec/km)	IEM - CO_2 ($g\times10^4$)	IEM - NO_x ($g\times10$)	IEM - PM (g)	IEM - VOC ($g\times10$)
Current Situation	287.39	144.10	19.99	267.08	206.98	92.40	142.42	202.07	254.85
Same Direction Without Signaling	156.69	83.16	29.39	137.03	238.42	81.37	116.76	198.56	180.70
Same Direction With Signaling	240.49	271.25	19.97	218.21	322.70	93.81	177.44	103.57	450.67
Reverse Direction Without Signaling	290.55	136.24	24.59	265.97	371.85	95.53	145.24	215.24	258.88
Reverse Direction With Signaling	322.32	325.66	25.37	298.87	404.70	98.97	178.46	80.23	544.08

Figure 13. Comparison of the simulation findings between five scenarios using analysed metrics (IEM means Instantaneous Emission Model)

Figure 13 illustrates the simulation output results for the various scenarios. In this figure, it is indicated that the minimum delay time occurs in the same direction scenario without a signal (287.39), while the maximum delay time is observed in the reverse direction with a signal. While it is seen that signalization increases the delay time, it is found that the modernization of Gürcükapı and Taşhan intersections reduces the delays. It can be attributed that this situation is due to waiting at red lights. Changing the direction at the intersection also contributes to the delays.

When examining the speed parameter, it is observed that the current scenario (19.99) and the same-direction scenario with signals (19.97) produce the lowest speeds. On the other hand, the opposite-direction scenarios without signals (24.59) and with signals (25.37) yield similar speeds, indicating that a certain level of improvement is achieved by changing the directions of the intersection arms. However, the scenario that allows the fastest movement is the same-direction scenario without signals. This suggests that changing the directions of the intersection arms does not provide significant benefits in terms of speed.

Similarly, the other parameters were obtained at least with the same direction scenario without a signal and at most with the reverse direction with a signal. This situation revealed that signalization increases queues, waiting time, travel time, and emissions (instant CO_2, NO_x, PM, and VOC), that the current situation is more efficient than the reverse direction of the junction arms, and that the modernization of the Gürcükapı and Taşhan junctions is effective on the mentioned parameters.

Figure 13 shows that the values for each parameter in the current situation and the unsignaled reverse direction scenarios are very close to each other. This means that the unsignaled reverse direction scenario is not likely to work and will only add to the costs. When the signaled same direction scenario is examined, it is found to be the second-best scenario for delay time, waiting time, and travel time; the second

worst scenario for average queue, instantaneous NO_x, VOC, and PM parameters; and the third worst scenario for instantaneous CO_2. The long travel times put pressure on the users participating in the traffic to reach the destination [41]. When this fact is combined with our findings, the fact that the scenario in question gives worse outputs than the current situation shows that it is meaningless to implement this scenario. The graph shows that the unsignaled same-direction scenario works at the Gürcükapı and Taşhan intersections, as well as on the roads that connect them. In this case, the study recommends implementing the scenario.

2.1. Comparison with other studies

In the study conducted by Çakıcı and Murat [13], a calculation method was developed for designing optimal signal timings and phase plans for approach lanes and flows around the roundabout. Although the study aligns with ours in the context of intersection optimization, its effectiveness was assessed by considering different intersection types and various phase plans, with delay as the primary performance criterion. This indicates a different perspective compared to our study. As such, it may serve as a valuable resource for future research aiming to evaluate intersection design from a broader perspective.

The findings of Bayata et al. [14] indicate that the Yıldız and Nedim Muratoğlu intersections in Erzincan should be designed as modern roundabouts to achieve optimal performance. Furthermore, for the Ergan Intersection, the study found no significant differences among the analyzed scenarios: signalized, four-leg (non-island), and modern roundabout designs. The study employed a decision-making methodology and, despite the evaluation of multiple alternatives, achieved successful results.

The study by Demiriz et al. [15] was carried out with the aim of alleviating the increasing traffic congestion in the city center of Erzincan, and therefore adopts a broad analytical perspective. In the study, 14 intersections were examined, and scenarios such as signal optimization, modern roundabouts, and grade-separated interchanges were evaluated. Using the Analytic Hierarchy Process (AHP), the most effective solution was identified as a combination of modern roundabouts and signal optimization.

Mecheva et al. [18] proposed a methodology that identifies the car-following model, routing algorithm, and their parameters, which best represent driving habits. This approach was implemented sequentially and in parallel using the urban mobility simulator SUMO and Python. The study offers opportunities to expand the methodology by incorporating additional adjustable components, such as lane-changing models or parameters. Their simulation-based solutions provide realistic and comprehensive results, with potential applications for intersection-based simulation studies in future research.

Zhang et al. [21] combined simulation-based optimization algorithms with Extreme Value Theory to optimize simulation calibration for large networks. This integration provided a framework for predicting traffic crashes through simulation. Their approach can serve as a guide for incorporating traffic safety considerations into intersection design in future studies.

3. Conclusion

The research designed four distinct scenarios that propose various geometric arrangements to improve the current situation at Gürcükapı and Taşhan intersections. These scenarios include four main options: signalized intersection, unsignalized intersection, signalized arm reverse intersection and a no-signal situation. Each scenario was compared with the current situation in terms of travel time, delay time, waiting time, speed, queuing and instantaneous emission values such as CO_2, NO_x, PM and VOC.

Following a thorough examination of the available data, it was determined that the option which demonstrated the most favourable performance of the four alternative scenarios presented a significant improvement in comparison to the current situation, particularly with regard to travel time, delay time and emission values. This scenario has been demonstrated to offer both an efficient travel experience and a reduction in traffic congestion

by considering traffic flow and environmental impacts. Consequently, Aimsun software was utilised as an effective tool in analysing and enhancing traffic networks at a micro scale, and the modelling process provided a significant solution for traffic management and environmental impact assessments. It is submitted that these findings can serve as a guide for local traffic policies and infrastructure development projects.

Article Information Form

Authors' Contribution

Conception / Design, Z. Zirek and M. A. Çolak; Data Collection, Z. Zirek and M. A. Çolak; Data Analysis / Interpretation, Z. Zirek and M. A. Çolak; Writing, Z. Zirek and M. A. Çolak; Technical Support / Material Support, Z. Zirek and M. A. Çolak; Critical Review of Content, Z. Zirek and M. A. Çolak; Literature Review, Z. Zirek and M. A. Çolak.

The Declaration of Conflict of Interest/ Common Interest

No conflict of interest or common interest has been declared by authors.

Artificial Intelligence Statement

No artificial intelligence tools were used while writing this article.

Copyright Statement

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