Research Article

Analysis of Signalized Roundabouts with Intelligent Transportation Systems - The Case of Gaziantep Junction 40 (Shell)

Abdulhalim BİLGİN[1,*], Caner PENSE[2]
[1] Intelligent Transportation Systems and Technologies, Institute of Science, Bandırma Onyedi Eylül University, Bandırma, Turkey
[2] Department of Transportation Engineering, Faculty of Engineering and Natural Sciences, Bandırma Onyedi Eylül University, Bandırma, Turkey
**Correspondence:* *abdulhalimbilgin@ogr.bandirma.edu.tr*
DOİ: 10.51513/jitsa.1481148

Abstract: This study presents an analysis aimed at optimizing traffic flow at the Shell Intersection in Gaziantep. Due to increasing population and vehicle numbers, traffic problems in the city are growing, especially at central intersections. Using PTV-Vissim micro-simulation software, the current situation was analyzed and alternative scenarios were developed. Performance analyses were conducted on models created using field observations and peak hour traffic counts. The intersection, currently at service level "F", is targeted to be elevated to service levels "B" and "C" through the proposed Single Point intersection design and optimized signal plans. Results indicate that the proposed changes could reduce average vehicle delay by 85-93% and increase average speed by 195-239%. This study aims to contribute to the improvement of urban traffic management through the integration of intelligent transportation systems and geometric arrangements.

Key words: Intelligent transportation systems, traffic simulation, traffic simulation software

Sinyalize Dönel Kavşakların Akıllı Ulaşım Sistemleri ile Analizi- Gaziantep 40 Nolu (Shell) Kavşağı Örneği

Özet: Bu çalışma, Gaziantep'teki Shell Kavşağı'nın trafik akışını optimize etmek amacıyla yapılan bir analizi sunmaktadır. Artan nüfus ve araç sayısı nedeniyle şehirdeki trafik sorunları giderek artmakta, özellikle merkezi kavşaklarda yoğunluk yaşanmaktadır. Çalışmada, PTV-Vissim mikro-simülasyon yazılımı kullanılarak mevcut durum analiz edilmiş ve alternatif senaryolar geliştirilmiştir. Saha gözlemleri ve zirve saat trafik sayımları kullanılarak oluşturulan modeller üzerinden performans analizleri gerçekleştirilmiştir. Mevcut durumda "F" hizmet seviyesinde olan kavşağın, önerilen Tek Nokta (Single Point) kavşak tasarımı ve optimize edilmiş sinyal planları ile "B" ve "C" hizmet seviyelerine yükseltilmesi hedeflenmiştir. Sonuçlar, önerilen değişikliklerin ortalama araç gecikmesini %85-93 oranında azaltabileceğini ve ortalama hızı %195-239 oranında artırabileceğini göstermektedir. Bu çalışma, akıllı ulaşım sistemlerinin entegrasyonu ve geometrik düzenlemeler yoluyla kentsel trafik yönetiminin iyileştirilmesine katkı sağlamayı amaçlamaktadır.

Anahtar Kelimeler: Akıllı ulaşım sistemleri, trafik simülasyonu, trafik simülasyon yazılımları

* Corresponding author.
E-mail address: abdulhalimbilgin@ogr.bandirma.edu.tr
ORCID: 0000-0003-2187-2193, 0000-0001-8743-196X (in hierarchical order)
Received 09.05.2024; Received in revised form 01.08.2024; Accepted 28.08.2024

1. Introduction

The rapid increase in urbanization and widespread vehicle ownership are causing traffic problems to escalate both globally and in Turkey. This situation brings about chronic traffic congestion, particularly in metropolitan areas, necessitating improvements in transportation infrastructure(Toğaç, 2023). According to data from the Turkish Statistical Institute (TUIK), the number of registered vehicles in the country increased from 631.000 in 1974 to 25.249.119 in 2021. This dramatic rise has led to a significant increase in the number of vehicles per 100 people, from 16.2 to much higher levels. The growth in car ownership is particularly noteworthy; automobiles, which constituted 49.6% of total vehicles in 1974, reached a proportion of 54.3% in 2021 (*TÜİK Kurumsal*, 2022).

In this context, the case of Gaziantep holds special significance. With a population exceeding 2 million and 645.243 vehicles, Gaziantep, Turkey's ninth-largest city, has a vehicle ownership rate of 0.3 per capita. This ratio indicates the potential severity of traffic congestion in the city. The increasing number of vehicles and traffic volume lead to serious disruptions, especially at intersections in urban centers, necessitating urgent solutions in traffic management and infrastructure improvements. At this juncture, Intelligent Transportation Systems (ITS) are gaining increasing importance. ITS technologies aim to optimize traffic flow in real-time, thereby reducing delays and emissions (Shahgholian and Gharavian, 2018).

The history of Intelligent Transportation Systems (ITS) dates back to the mid-20th century, beginning with traffic control systems that utilized roadside sensors to monitor parameters such as speed and traffic density. In the 1990s, the technology and scope of these systems expanded significantly under the ITS framework. ITS encompasses innovative solutions such as adaptive signal control, optimization of urban road networks, and communication between autonomous vehicles.

Due to the anticipated environmental and economic benefits, the implementation of ITS has become central to sustainable urbanization and the concept of green cities. Environmentally friendly transportation solutions contribute to the fight against climate change by reducing carbon emissions. Additionally, ITS plays a crucial role in reducing traffic accidents and the resulting human and material losses.

From this perspective, the development and application of ITS technologies have become an indispensable requirement for modern cities. ITS aims to create a more efficient, safe, and environmentally friendly transportation network not only for road users but also for public transportation systems and entire cities. In this context, the Gaziantep 40 Nolu (Shell) Intersection serves as a concrete example of the solutions ITS offers to urban traffic problems.

Particularly, signalized roundabouts play a critical role in managing high traffic volumes. However, in Turkey, the integration of signalized roundabouts with ITS is not yet widespread, and academic studies on this subject are limited. Therefore, analyzing one of the busiest intersections in Gaziantep, the Shell intersection, from an ITS perspective, could provide valuable insights for optimizing traffic flow and reducing congestion.

This study aims to contribute to the literature by addressing signalized roundabouts with a holistic approach, optimizing both signaling and geometric elements, and ensuring real-time and dynamic management through ITS integration. Intelligent Transportation Systems have the potential to significantly contribute to the effective and sustainable management of urban traffic.

2. Literature Review

Various studies conducted in Turkey and other countries demonstrate the effectiveness of micro-simulation and signal optimization programs in intersection arrangements.

In a 2012 study conducted in Konya, the current situation of the Kule, Nalçacı-Sille, and Kabataş intersections was analyzed, and using the Sidra micro-simulation program, a 35% reduction in average delay times, a 20% reduction in degrees of saturation, and a 25% increase in capacity were achieved (Akmaz. M., 2012).

In a 2017 study at the 100th Year Intercity Bus Terminal intersection in Zonguldak, the impact of vehicle delays caused by signal timing on harmful gas emissions was examined, and using the Sidra Intersection micro-simulation program, a 22% reduction in fuel consumption, a 35% reduction in CO emissions, and a 12% reduction in NOx emissions were obtained (Zeydan , 2017).

In a 2018 study at an intersection on the Erzurum-Bingöl state road in Erzurum, using the PTV Vissim micro-simulation program, a 35% reduction in delay time, an 83% reduction in queue length, and a 23% reduction in harmful gas emissions were achieved (Bas ., 2020).

In a 2019 study at the Al-Fallah intersection in Baghdad, using the Synchro signal optimization program, an 87% reduction in average delay and an improvement in the level of service from F to D were achieved (Ziboon, A.R.T, 2019). The study analyzes the impact of vehicle delays at signalized intersections on the traffic system in Sakarya in 2017 using VISSIM simulation software.

A signalized intersection in Sakarya was examined in the research, and the effects of increases in vehicle types and quantities on average delay times were observed. The results indicate that irregular urbanization and rising vehicle ownership complicate transportation issues, emphasizing the importance of improvements in public transportation systems and intelligent signalization systems (Aktaş, Aslan and Pistil, 2017).

A study conducted in 2022 emphasizes the necessity of developing delay and queue length calculation methods at signalized intersections, particularly in underdeveloped and developing countries, to suit local traffic conditions. The situation in Turkey was examined at six different signalized intersections in Antalya, revealing that existing methods (HCM 2010 and Australian (Akçelik) methods) exhibit high error rates (64.5% for delay and 40.9% for queue length). It was concluded that new delay and queue length calculation methods tailored to the traffic culture and intersection geometric characteristics of countries like Turkey need to be developed (Aydın, Aydoğdu and Yıldırım, 2022).

A study conducted in 2015 introduced a new approach to determining saturation flow, a critical parameter in the design of signalized intersections. Two existing methods, analytical and observational, are accepted by the HCM. The new method developed in this study was tested at various intersections in Izmir. Variables such as vehicle length, distance between vehicles, driver reaction time, acceleration rate, acceleration duration, and intersection crossing speed were used in this method. Many of these variables are related to driver behaviors. The results indicate that the proposed method provides positive outcomes in determining saturation flow and identifying the impact of driver behaviors (Çetin, 2015).

In a study conducted in 2015, a mathematical model was developed to simulate traffic flow at signalized intersections. The study, based on video camera observation data, examines how traffic flow changes over time and distance starting from congestion density. The intersection was divided into four zones of twenty meters each, with a stop line at the rear. The model consists of a set of curves based on the congestion density information in the first zone, allowing the determination of traffic densities at various times and zones. The error analysis conducted demonstrated that the standard error between the model results and the observation data was within an acceptable range (Sönmez, 2015).

In a 2004, study various control strategies to improve traffic congestion on urban road and highway networks were examined. The authors highlighted the deteriorative effects of traffic congestion on infrastructure and the resulting decrease in efficiency. Based on various application results, the study evaluated the proposed strategies for different areas such as urban road networks, highways, and route guidance. It was shown that methods like ramp metering play a significant role in preventing traffic congestion by enhancing efficiency (Papageorgiou *et al.*, 2004).

A 2001 study addresses conceptual and scientific issues critical to traffic management and control in intelligent transportation systems using dynamic traffic assignment and simulation methodologies. The study defines and evaluates Dynamic Traffic Assignment (DTA) systems in the context of real-time information-based traffic control strategies and user response models. The DYNASMART simulation-assignment model successfully represents traffic flow processes at both microscopic and macroscopic levels, enabling the analysis of the effectiveness and operational applications of ITS Technologies (Mahmassani, 2001).

In a 2001 study, a comprehensive review of traffic flow modeling approaches was conducted, examining Mainstream Flow Models (Microscopic, Mesoscopic), Traffic Density Conservation, Model Calibration, and Validation. The study addresses different modeling approaches for understanding and managing traffic flow models, discussing the advantages and disadvantages of these approaches (Hoogendoorn and Bovy, 2001).

In traffic engineering, safety has become a widely evaluated and continuously improved topic. However, the lack of good models that can predict accident potential makes it difficult to assess the safety of new traffic regulations. A 2003 study focuses on the evaluation of indirect safety measures derived from existing traffic simulation models. Indirect safety measures such as Time to Collision (TTC), Post-Encroachment Time (PET), and deceleration rate emerge as important tools in traffic safety assessments. The study demonstrates the effectiveness of indirect safety measures using VISSIM-SSAM-based models to predict pedestrian accidents in India. Indirect safety measures allow for the examination of areas before accidents occur, eliminating the necessity of collecting accident data (Gettman, 2003). VISSIM, introduced in 1994, is a microscopic, behavior-based, and multi-purpose traffic flow simulator. This simulator offers a wide range of applications for urban and highway use, providing integration of public and private transport. The core traffic flow models include longitudinal and lateral movements of vehicles on multi-lane roads, conflict resolution models on overlapping trajectories, and the social force model applied to pedestrians. It is emphasized that traditional methods are insufficient for the validation of autonomous driving functions and need to be supported by simulations. Vehicle following and lane-changing models, especially the Wiedemann model, are used to enhance the accuracy of autonomous vehicle simulations. VISSIM plays a significant role in analyzing the impacts of autonomous vehicles and in safety assessments (Fellendorf and Vortisch, 2011).

A 2000 study evaluates the effectiveness of traffic simulation models in the development of Intelligent Transportation Systems (ITS). Multi-modal microscopic simulation approaches, incorporating comprehensive vehicle-following and lane-changing logic, were used in different traffic scenarios. Comparisons with TSIS/CORSIM and WATSim models revealed that only the INTEGRATION model could simulate U-turns but was insufficient in modeling complex signal operations. Additionally, the relationships between vehicle travel times, delays, and the number of stops were investigated in a static signal network examined using TRANSYT and INTEGRATION models (Boxill and Yu, 2000).

CARSIM, developed to realistically simulate both normal traffic flow and stop-and-go conditions, is a vehicle-following simulation model that considers safe distances between vehicles, start-up delays, and randomly generated driver reaction times. The model accounts for dual behaviors in both congested and uncongested traffic conditions. The validity of the model was tested at both microscopic and macroscopic levels, showing high agreement with speed change patterns and location data based on field data (Benekohal and Treiterer, 1988).

In a 2011 study, Akçelik evaluates the roundabout capacity model from the 2010 Highway Capacity Manual (HCM 2010). It is noted that this model, designed specifically for the U.S. and based on the NCHRP 572 report, is a nonlinear empirical (regression) model. Akçelik points out that the model used in SIDRA INTERSECTION software closely aligns with HCM 2010, but U.S. roundabouts have lower capacities compared to those in Australia and the U.K. He also highlights potential future increases in U.S. roundabout capacities due to changes in driver behavior (Akçelik, 2011).

A 2019 study analyzed traffic congestion in the Gölcük Corridor of Kocaeli province using PTV Group VISSIM software. The research examined the impact of separating transit traffic from local traffic on traffic flow and compared two different solutions. The first solution focused on maintaining continuity for transit traffic while providing urban connections via side roads. The second solution involved adjusting signal timings and phase plans at existing intersections. Results indicated that both solutions had positive effects compared to the current situation, but phase adjustment was more effective (ILICALI and SARAÇ, 2019).

A study on the formulation of traffic signalization in Turkey emphasizes the need to develop signalization formulas suited to local traffic conditions. The study indicates that foreign formulas are not suitable for Turkey and that local conditions must be considered. In this context, new formulas for calculating green light and period durations for intersections in Turkey were developed. The adverse effects of heavy vehicles and minibuses on traffic were highlighted, and their impact on green light durations was included in the calculations (Özdirim, 1972).

Due to the inadequacy of traditional delay determination methods, this study highlights the importance of traffic volume, red light waiting times, and the number of vehicles in the queue as significant parameters. By incorporating these parameters into the model, the study aims to optimize traffic signalization at intersections. The model compared fixed-time and traffic-responsive signalization systems, indicating a preference for traffic-responsive systems. The results suggest that these model simulations were effective in improving intersection performance, and future enhancements with artificial intelligence are recommended (Simsir, Ozkaynak and Ekmekci, 2013).

The environmental impacts of waiting vehicles at signalized intersections were evaluated through a four-phase intersection. CO2 equivalent emission values were calculated, examining the impact of idle stop-start systems and electric vehicles on emissions. Results showed that even a small increase in the number of electric vehicles and the use of idle stop-start systems could significantly reduce CO2 equivalent emissions (Arabaci *et al.*, 2020).

A study conducted at the Adnan Kahveci Signalized Intersection in Ankara used traffic observation and counting methods to analyze the intersection's capacity and delays. These analyses were performed based on the existing cycle time and the newly calculated cycle time, using various capacity analysis methods such as Webster Method, Highway Capacity Manual (HCM 1985), Australian Method, and Sidra Intersection 3.2 Program. The results showed that the data obtained using the Sidra Intersection 3.2 Program were very close to the observations (Çetinkaya, 2008).

Based on the insights gathered from the literature, it is evident that various simulation and optimization tools, such as Sidra, VISSIM, and Synchro, have been effectively employed to analyze traffic dynamics at signalized intersections, assess delay times, and evaluate environmental impacts. These studies emphasize the necessity of tailored approaches to traffic management that accommodate local traffic conditions, urbanization patterns, and driver behaviors.

Building on this foundation, this study focuses on optimizing traffic flow at the Shell Junction in Gaziantep utilizing the PTV Vissim micro-simulation software, in order to solve problems such as increased waiting times and traffic congestion by analyzing traffic conditions and developing alternative scenarios to enhance junction performance.

3. Material and Method

This study was conducted at the 40 Nolu (Shell) Junction located in Gaziantep, which is a strategic point with heavy urban traffic and frequent passage of various vehicle types. During the data collection process, critical variables such as traffic volume, vehicle speeds, and vehicle types were gathered. These data were utilized to better understand the traffic flow at the junction and to determine the necessary parameters for simulation modeling. Data collection was carried out through traffic cameras and installed sensors during specific time intervals and on different days, followed by analysis.

The level of service (LOS) of an intersection is a measure of the quality affected by various factors, including traffic volumes, speed and travel time, traffic interruptions, maneuverability, safety, vehicle driving comfort, and operating costs. In evaluating the traffic flow at the junction, the LOS values from the Highway Capacity Manual (HCM) (Fig. 7) were employed. The LOS levels, ranging from A to F, were analyzed as follows:

- **Level of Service A (LOS A):** Represents conditions with low traffic volumes and high speeds, indicative of free-flowing traffic.
- **Level of Service B (LOS B):** Operating speed starts to be somewhat restricted due to traffic conditions. Drivers still have reasonable freedom in choosing their speed and lane.
- **Level of Service C (LOS C):** Speed and maneuverability are more controlled due to high traffic volumes. Drivers' freedom to choose their own speed, change lanes, or overtakes is limited.
- **Level of Service D (LOS D):** Approaches unstable flow and is significantly affected by variations in operating conditions but can still provide an acceptable operating speed.
- **Level of Service E (LOS E):** Cannot be described solely by speed but indicates lower operating speeds and operation at or close to capacity.
- **Level of Service F (LOS F):** Describes forced flow conditions and low-speed operations when volume is below capacity.

In this study, the impact of factors such as traffic volume, speed, and maneuverability freedom on determining the levels of service was considered, and the current status of the junction was thoroughly evaluated based on the collected data. The gathered data were processed and analyzed using PTV-Vissim simulation software. During this process, various verification and validation steps were taken to ensure the accuracy and reliability of the data.

3.1. Signal Timing Optimization

Signal timing optimization involves arranging the durations of traffic lights and phase plans in the most optimal way to maximize traffic flow efficiency. This process aims to minimize average vehicle delays, stop times, and waiting times at intersections. Signal timing optimization is widely used in urban traffic management, highway intersections, signalized roundabouts, and other signalized traffic control systems. This optimization is applied to improve urban traffic flow, enhance road safety, and reduce vehicle fuel consumption.

3.2. Methods Used

Common methods used in signal timing optimization include adaptive control systems (SCATS, SCOOT), fixed-time control, phase and signal timing optimization, and heuristic and mathematical models (Webster, Akçelik methods). Adaptive control systems respond instantly to traffic density, while fixed-time control is easier to implement but cannot respond to changes in traffic density. Heuristic and mathematical models theoretically provide the most optimal signal timings but lack flexibility in real-time applications.

3.3. Simulation Model

PTV-Vissim software stands out with its detailed micro-simulation capabilities, flexibility, and user-friendly interface, especially in areas with heavy traffic flow (Cakici and Murat, 2015). This software allows for detailed modeling of individual vehicle movements and interactions and has the flexibility to simulate different traffic scenarios (Çakıcı & Murat, 2020). Additionally, PTV-Vissim ensures that simulations are realistic and reliable by integrating real-world data (Murat and Cakici, 2017). Compared to other traffic simulation software, the detailed analyses and data integration capabilities offered by PTV-Vissim make it more advantageous.

Methods used for signal timing optimization include the Webster method, the Akçelik method, genetic algorithms, and fuzzy logic. The Webster method is used to minimize average delay at signalized intersections (Webster, 1958), while the Akçelik method, developed by calibrating the 1985 HCM delay formula, aims to reduce vehicle delays at isolated signalized intersections (Akçelik, 2005). Genetic algorithms evaluate different combinations of signal timings to find the optimal solution, while fuzzy logic is used to model traffic flows that involve uncertainty and complexity (Çakıcı & Murat, 2020).

In terms of geometric arrangements, factors such as the number of circulation lanes in signalized roundabouts, optimization of phase plans, and adequacy of storage areas are examined.(Cakici and Murat, 2015) found that average vehicle delays increase in three-lane arrangements due to weaving areas. Optimization of phase plans aims to minimize delays by regulating traffic flow at intersections (Çakıcı & Murat, 2020), while inadequate storage areas can lead to traffic congestion and delays.

In conclusion, PTV-Vissim software is widely preferred in traffic engineering studies due to its detailed micro-simulation capabilities, flexibility, and user-friendly interface. The methods used for signal timing optimization and geometric arrangements aim to regulate traffic flow and minimize delays, and the theoretical foundations of these methods are extensively covered in the traffic engineering literature.

3.4. Model Setup and Parameters

The model setup was carried out using data collected from field studies. The vehicle volume and turning percentages at the intersection during peak hours were determined, and modeling studies were initiated by observing the existing signal programs and traffic flow. Parameters included in the simulation model are vehicle volume, turning percentages, signal timings, traffic flow, intersection geometry, and vehicle types.

3.5. Data Input and Calibration

The data used in the model was collected through field studies and traffic counts conducted during peak hours. The collected data was compiled in terms of passenger car units and used as input for the model. To ensure the accuracy of the model, real traffic data was compared with simulation results, and performance parameters such as vehicle delays, stop times, and speeds were validated with observations, and necessary adjustments were made.

3.6. Geometric Arrangements - Current Situation and Recommendations

The Gaziantep Shell Intersection is a signalized intersection with four approach arms and a roundabout island. The intersection is located at the intersection of D-400 Sani Konukoğlu Boulevard with Çetin Emeç Street, Ömer Ersoy Street, and other main roads. Currently, the approach arms operate with a flashing signal plan, and there are no signal poles within the island. The existing geometric arrangements of the intersection can negatively affect traffic flow, especially during peak hours. The inadequacy of left-turn pockets can cause delays at the intersection as turning vehicles obstruct the straight-moving vehicles.

Recommended geometric arrangements include revising signal plans, expanding storage areas, and increasing the number of lanes. These arrangements can reduce delays and increase the capacity of the intersection by making traffic flow more orderly. Additionally, they can help reduce accidents by improving traffic safety.

4. Study Area

Gaziantep, one of the developed cities in the Southeastern Anatolia Region, covers an area of 6,887 km^2 and has a city center population of 2,154,051 (*TÜİK Kurumsal*, 2022)). Its geopolitical significance is enhanced by its location on the historic Silk Road. The city is accessible by road and air. This study focuses on Gaziantep's Iller Junction 40 (Shell), which handles approximately 4,507 vehicles. The Junction 40 (Shell), one of the busiest in Gaziantep, is located within the Şehitkamil District boundaries and intersects the D-400 Sani Konukoğlu Boulevard. It is a multilayered junction with four approach arms and roundabouts, currently operated with flash signal plans, and lacks signal poles within the island. The junction is a critical intersection point for many important locations and main arteries.

4.1. Junction 40 (Shell)

The Junction 40 (Shell), located within the boundaries of the Şehitkamil District and intersecting the D-400 Sani Konukoğlu Boulevard, is a multilayered intersection with four approach arms and roundabouts. It operates under a flash signal plan for the approach arms, and there are no signal poles within the island. The satellite image of the junction is provided in Figure 1. Due to its position at the intersection of several key points and main arteries, the junction is heavily used.

Figure 1. Junction 40 (Shell)

4.2. Traffic Counts

Traffic counts at the Junction 40 (Shell) were conducted on the 16th of June, 2022, during the morning hours of 07:00 to 09:00 and the evening hours of 17:00 to 19:00. The enumerations used for the junction counts are provided in Figure 2. Accordingly, approach number 1 represents the D-400/Courthouse direction, approach number 2 the D-400/Train Station direction, approach number 3 the Olay TV Junction direction, and approach number 4 the Ömer Ersoy Street direction.

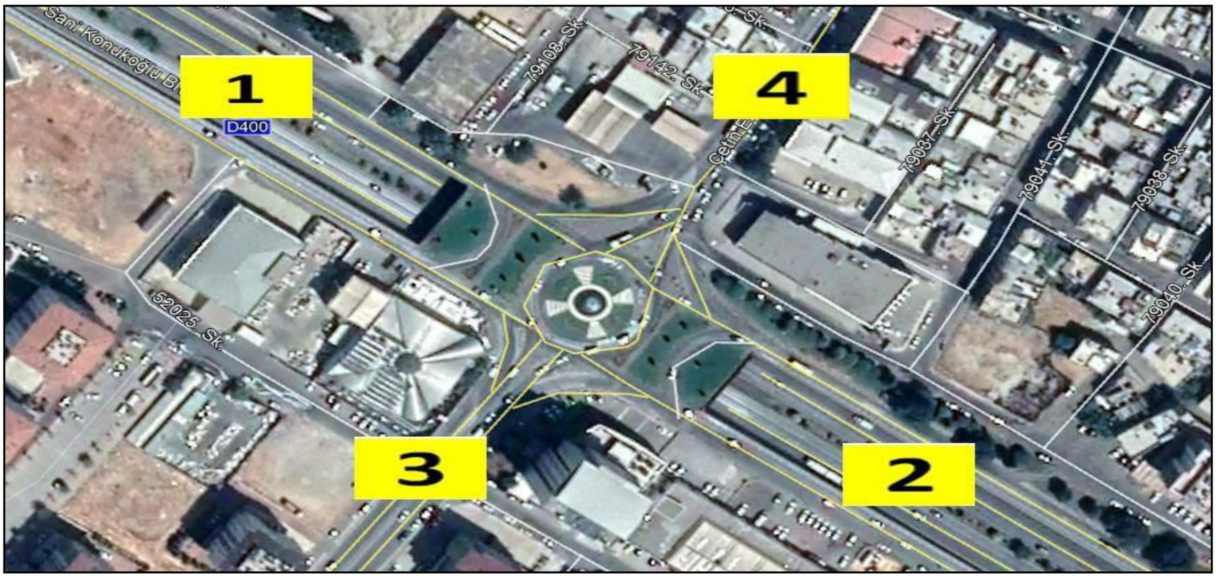

Figure 2. Approach arms and their numbering

The counts conducted at the intersection were compiled for a full hour in passenger car units (pcu) based on the peak hour interval and included in the report. The tables prepared accordingly are presented below. The traffic volume values calculated for the morning peak hour at the Junction 40 (Shell) are provided in Table 1. According to this, while the peak hour volume of the junction was calculated as 3,584 pcu/hour, the busiest approach was identified as approach number 1 (Çetin Emeç Street), which is the direction coming from the Ömer Ersoy Street.

Table 1. Traffic measurements for the morning peak hour

	1	**2**	**3**	**4**	**TOTAL**
1	0	94	25	527	646
2	315	0	130	357	802
3	166	192	0	325	683
4	653	542	258	0	1.453
				GRAND TOTAL	**3.584**

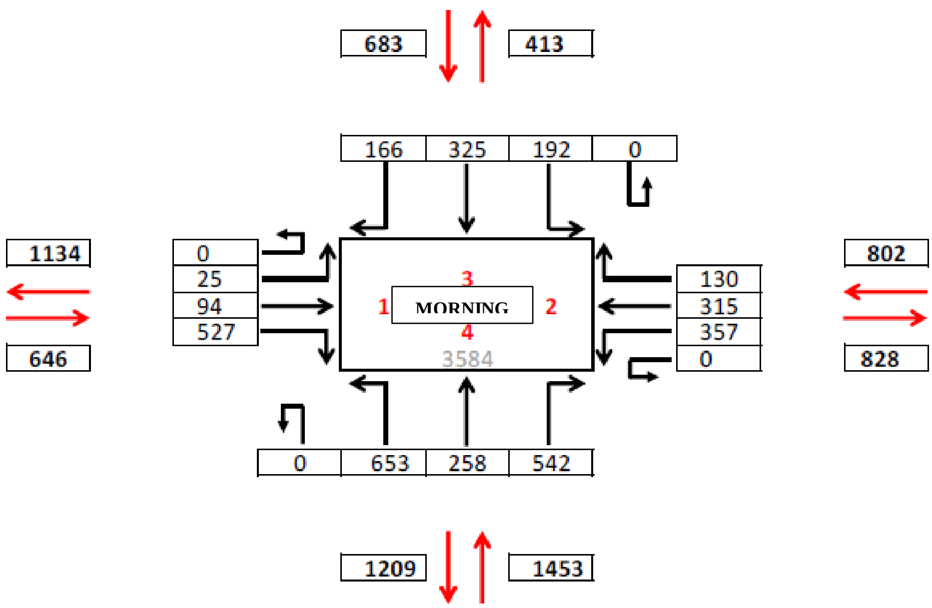

Figure 3. Traffic Volume Diagrams for the 40th (Shell) Junction During Morning Peak Hours

The percentages of vehicle movements at the junction were also calculated for the morning peak hour and are provided in Table 2. Accordingly, the internal mobility within each arm of the Junction 40 (Shell) was determined, and the most and least frequent movements were identified. Based on this data, a foundation has been established for interventions that will not incur physical costs, such as modifications in turn restrictions or phase plans.

Table 2. Movement percentages at the junction (morning peak hour)

	1	2	3	4	TOTAL
1	0%	14%	4%	82%	100%
2	39%	0%	16%	45%	100%
3	24%	28%	0%	48%	100%
4	45%	37%	18%	0%	100%

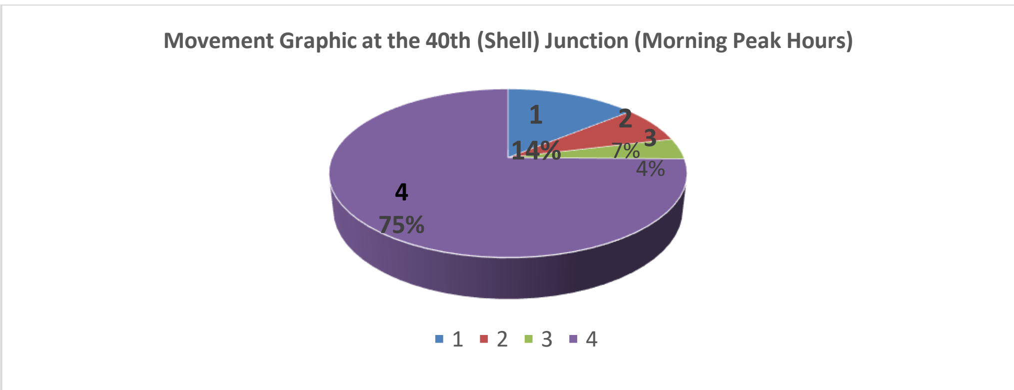

Figure 4. Movement Graphic at the 40th (Shell) Junction (Morning Peak Hours)

The traffic volume values for the Junction 40 (Shell) during the evening peak hour are presented in Table 3. It has been determined that the volume at the junction during the peak hour was calculated as 5,430 pcu/hour, with the busiest approach being approach number 1, which is the direction coming from the Courthouse.

Table 3. Traffic measurements for the evening peak hour

	1	**2**	**3**	**4**	**TOTAL**
1	267	130	80	1.380	1.856
2	276	672	267	290	1.506
3	204	135	0	643	982
4	429	435	222	0	1.087
		GRAND TOTAL			**5.430**

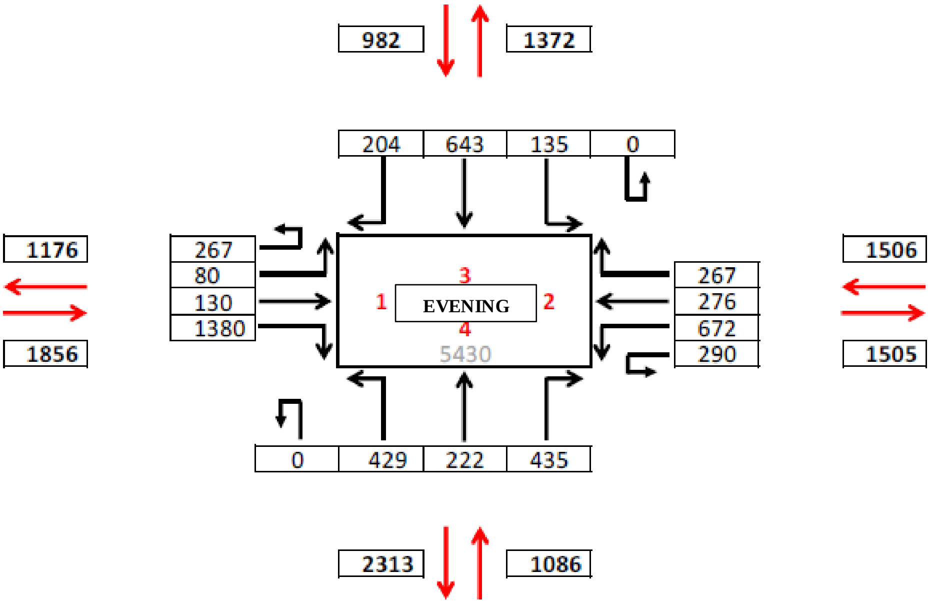

Figure 5. Traffic Volume Diagrams for the 40th (Shell) Junction During Evening Peak Hours

The percentages of vehicle movements at the junction for the evening peak hour have been calculated and are shown in Table 4. Accordingly, the movement within each arm of the Junction 40 (Shell) was identified, highlighting the most and least frequent maneuvers. This information has laid the groundwork for non-costly physical interventions, such as adjustments to turning restrictions or phase schedules.

Table 4. Movement percentages at the junction (evening peak hour)

	1	**2**	**3**	**4**	**TOTAL**
1	14%	7%	4%	75%	100%
2	18%	45%	18%	19%	100%
3	21%	14%	0%	65%	100%
4	40%	40%	20%	0%	100%

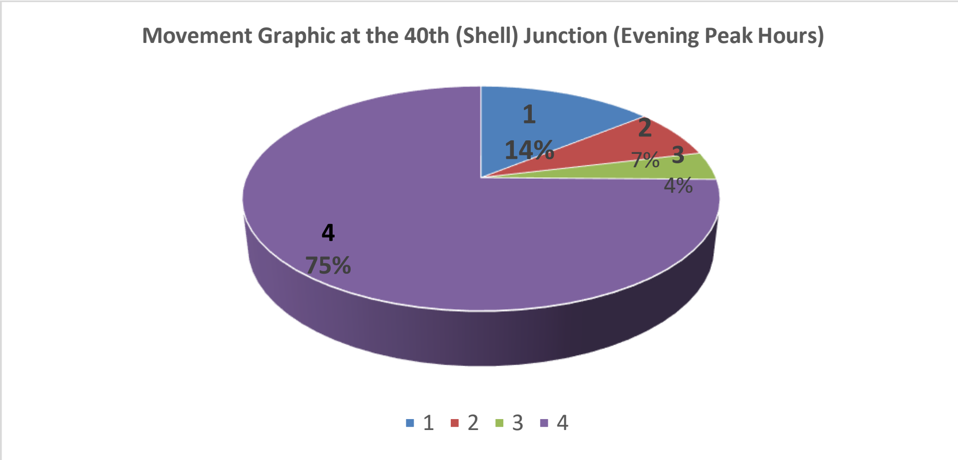

Figure 6. Movement Graphic at the 40th (Shell) Junction (Evening Peak Hours)

In addition to the traffic counts at the intersection, it has been determined that a flash signal plan is implemented within the roundabout and on the approach arms. Besides the junction counts and the signal programs implemented, another factor affecting the junction's performance is the observed excess volume at the junction due to the underuse of the underpass for straight-through movements on the East-West axis, leading to increased use of the junction for direct crossings.

5. Establishing the Traffic Model

Development of the Traffic Model for Junction 40 (Shell): Initially, in the process of developing the traffic model for Junction 40 (Shell), field surveys were conducted to establish vehicle volumes and turning movement percentages during peak traffic periods. Signal schedules active at the junction were also documented. Additionally, junction inefficiencies were identified through on-site observations, setting the stage for detailed modeling activities.

A three-dimensional representation derived from the model of Junction 40 (Shell)'s current state during the morning peak period is illustrated in Figure 3. As indicated in the figure, problematic traffic conditions are attributed to excessive and unregulated roadside parking on the approach from Olay TV Junction (Approach 3 – Ömer Ersoy Avenue) and towards the Ömer Ersoy Street (Approach 4 – Çetin Emeç Avenue). The adverse impact of this parking situation on traffic flow, along with the roundabout's insufficient capacity, has been verified through both quantitative and visual data.

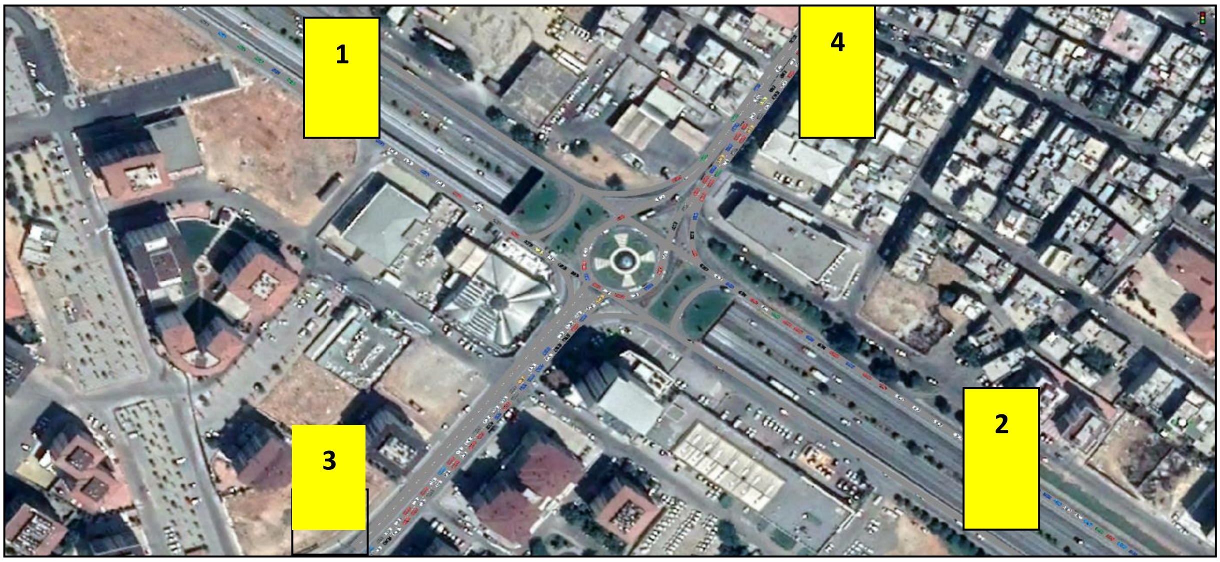

Figure 7. A three-dimensional view from the model established for the junction during the morning peak hour (1,500/3,600 seconds)

The performance analyses for the Junction 40 (Shell) during the morning peak hour in its current state are provided in Table 5.

Table 5. Performance analysis of the current state during the morning peak hour

Paramet er	Current Situation Morning Peak Hour
Average Delay per Vehicle (Sec/Veh)	254
Average Stop Delay per Vehicle (Sec/Veh)	153
Average Number of Stops per Vehicle	5
Average Speed (Km/H)	5,60
Total Number of Stops	10.724

The three-dimensional image derived from the model for the Junction 40 (Shell) during the evening peak period is presented in Figure 6. It is evident from the figure that, similar to the morning peak period, congestion occurs on the approach from Olay TV Junction (Approach 3 – Ömer Ersoy Avenue) and towards the Ömer Ersoy Street (Approach 4 – Çetin Emeç Avenue). This congestion leads to a stagnation of traffic within the roundabout, adversely affecting traffic flow as confirmed by both quantitative and visual data.

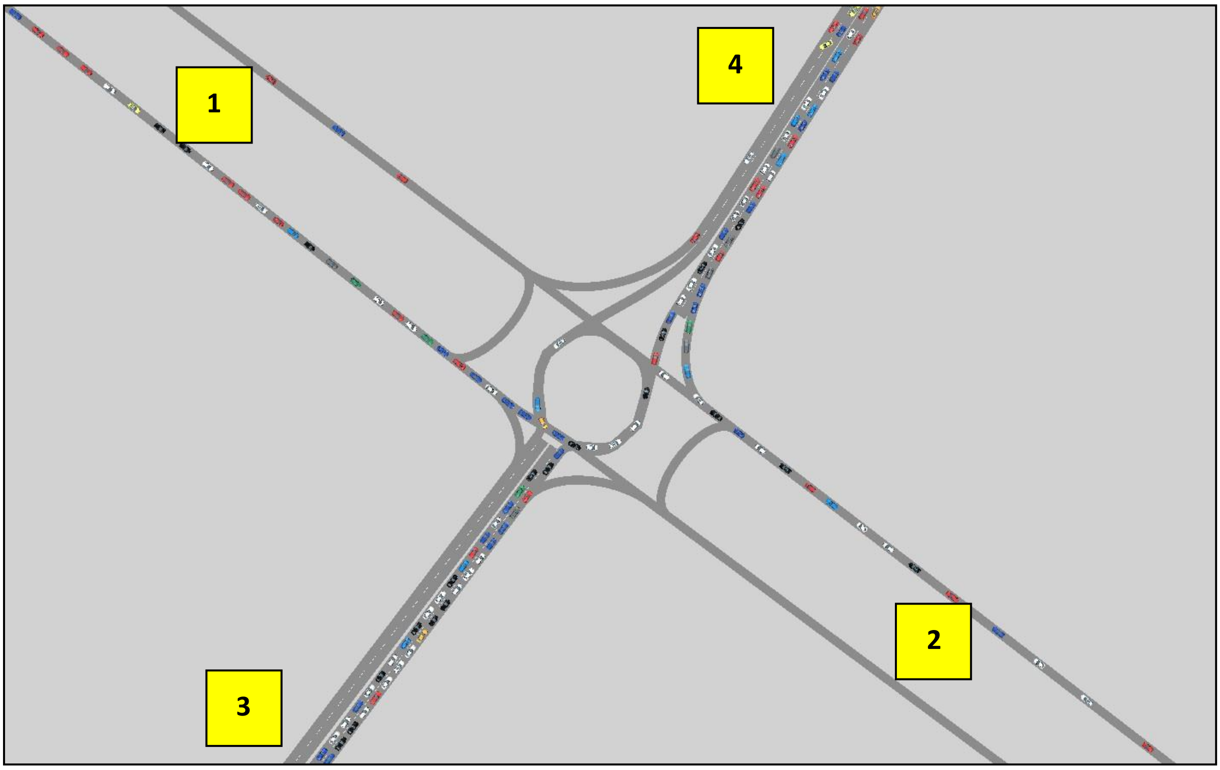

Figure 8. A three-dimensional view from the model established for the junction during the evening peak hour (1,500/3,600 seconds)

The performance analyses for the Junction 40 (Shell) during the evening peak hour in its current state are provided in Table 6.

Table 6. Performance analysis of the current state during the evening peak hour

Parameter	**Current Situation** Evening Peak Hour
Average Delay per Vehicle (Sec/Veh)	229
Average Stop Delay per Vehicle (Sec/Veh)	138
Average Number of Stops per Vehicle	5
Average Speed (Km/H)	6,46
Total Number of Stops	10.600

6. Capacity Analysis

Observations made on-site, collected data, existing maps, and traffic counts have been utilized to model the designated intersections and corridors using PTV VISSIM traffic micro-simulation software, through which current conditions and capacity analyses have been conducted. In the capacity analyses, the average delay times per vehicle at intersections and the corresponding service levels have been reported.

The service levels corresponding to the calculated delays at intersections have been determined using values from the Highway Capacity Manual (HCM). These mentioned values are provided in Table 7.

Table 7. HCM Service Level Ranges

Service Level	Signalized Intersection	Non-Signalized Intersection
A	<10 sec.	<10 sec.
B	11-20 sec.	11-15 sec.
C	21-35 sec.	16-25 sec.
D	36-55 sec.	26-35 sec.
E	56-80 sec.	36-50 sec.
F	>80 sec.	>50 sec.

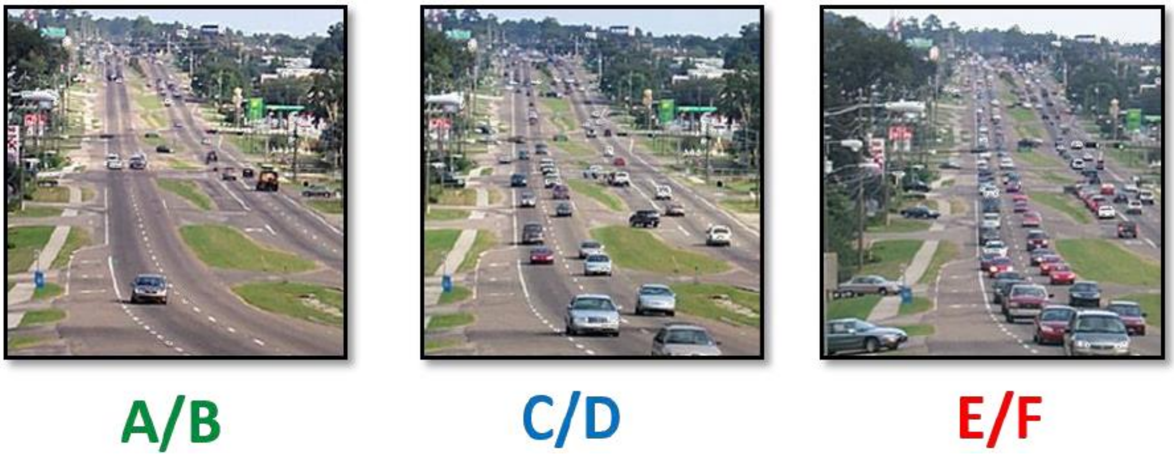

Figure 9. Example representation of service level ranges

Analyses conducted with consideration to the Highway Capacity Manual (HCM) criteria indicate that movements with service levels "E" and "F" are those where the volume to capacity ratio is 1 or greater. The purpose of identifying these movements is to facilitate the improvement of these bottlenecks in future studies through proposed solutions.

7. Identification of Problems and Proposed Solutions

The current state of the Junction 40 (Shell) has been modeled for both morning and evening peak hours, and performance analyses for these peak periods have been conducted. Based on the data obtained and field observations, the following issues have been identified:

- The inadequacy of the existing lane numbers and storage at the approach arms of the junction during the evening peak hours, due to vehicle volumes exceeding 5,000 passenger car units,
- The increase in junction volume caused by vehicles choosing not to use the D-400 highway for through passage and instead passing through the junction,
- Roadside parking up to the approach mouths of Çetin Emeç and Ömer Ersoy Avenues nearly halting traffic flow,
- The lack of sufficient storage capacity within the roundabout,
- Traffic negatively impacted by weaving caused by driver errors such as failure to follow lanes and incorrect lane-changing movements.

The problems with the current state have been identified, and scientifically viable solutions have been proposed. In this regard:

1. Restricting the Adliye – Gar passage (1-2 / 2-1) over the junction to enhance the efficiency of the D-400 through passage and reduce traffic volume at the junction (See Figure 8),
2. Removing the roundabout system in favor of transitioning to a Single Point Intersection design (See Figure 8),
3. Replacing the flash signal plan with a three-phase signal plan,
4. Restricting roadside parking at the approach mouths of Çetin Emeç and Ömer Ersoy Avenues,

have been suggested as solutions to the problems and modeled according to alternative scenarios. A two-dimensional drawing of the proposal scenario is provided in Figure 10.

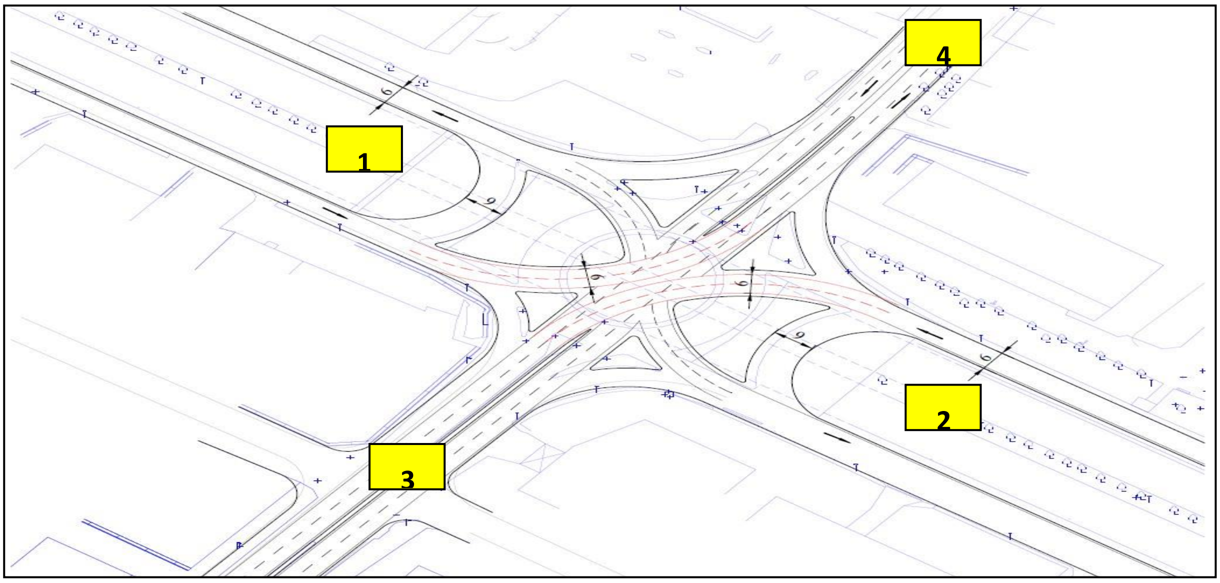

Figure 10. Planned new intersection design for Junction 40 (Shell)

7.1. Alternative Scenario and Performance Analysis

Two alternative scenarios have been explored for the Junction 40 (Shell). Given the presence of an underpass at the junction, modifications have been made to parameters such as the number of lanes on side roads, constrained by physical boundaries like the underpass structures, to study various alternatives.

7.2. Analysis of Alternative-1 Scenario

A traffic model for the current state of the Junction 40 (Shell) has been established, existing problems identified, and accordingly, some solution proposals have been developed. The testing of these solutions within the traffic model and their performance outcomes are presented under this section. In this alternative for the junction, while the side roads of the D-400 Highway physically accommodate a lane width of 6 meters operating as a single lane in one direction (1x1), they have been modified to operate as two lanes in one direction (1x2).

For the junction, which currently operates with a flash signal plan, the ALT - I scenario envisages a "Single Point (Single Point)" junction design and plans to operate it with a three-phase signal plan. The circuit diagrams planned for the junction are provided in Figures 10 and 11. A period of 80 seconds has been determined for the morning peak hour, while for the evening peak hour, this duration has been set to 82 seconds.

The anticipated phase plans for the morning and evening peak hours under the ALT - I scenario for Junction 40 (Shell) are given in Figure 10. By designating the junction design as Single Point, the junction, which operates with a flash signal plan on its approach arms in the current state, has been operated with three phases.

Table 8. Predicted phase plan for the morning peak hour in Alternative – I scenario

Alternative-1		Phase Plan (Green Times)			
		*M.P.T.**	Period S.	E.P.T.*	Period S.
Junction 40 (Shell)	D/400-Adliye	20 sec.	80 sec.	24 sec.	82 sec.
	D/400-Gar	20 sec.		24 sec.	
	Olay TV	20 sec.		20 sec.	
	Ömer ERSOY	24 sec.		20 sec.	

* *M.P.T. = Morning Peak Time*

** *E.P.T. = Evening Peak Time*

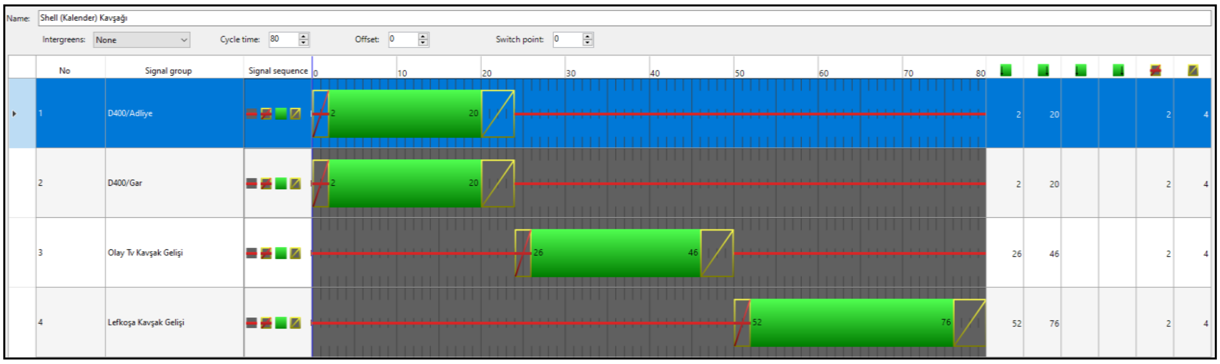

Figure 10. ALT - I scenario, the circuit diagram planned for the morning peak hour

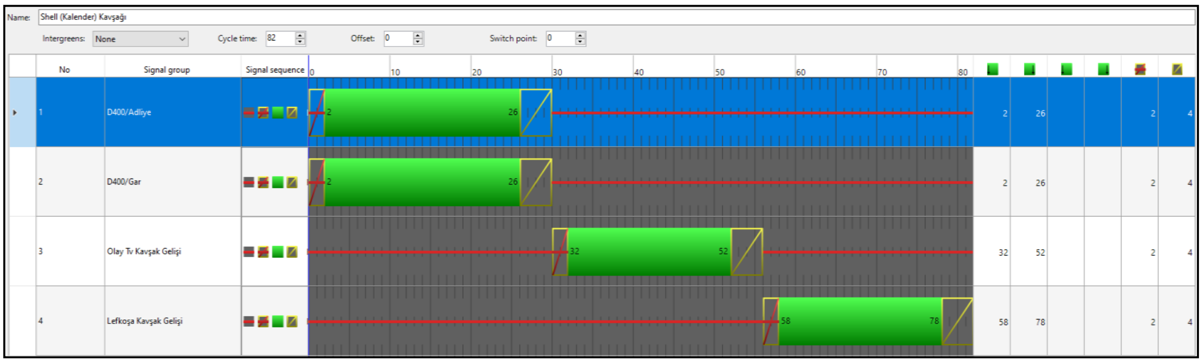

Figure 11. ALT - I scenario, the circuit diagram planned for the evening peak hour

The two-dimensional visuals for the morning and evening peak hours taken from the Alternative - I model are provided in Figure 12 and Figure 13**.**

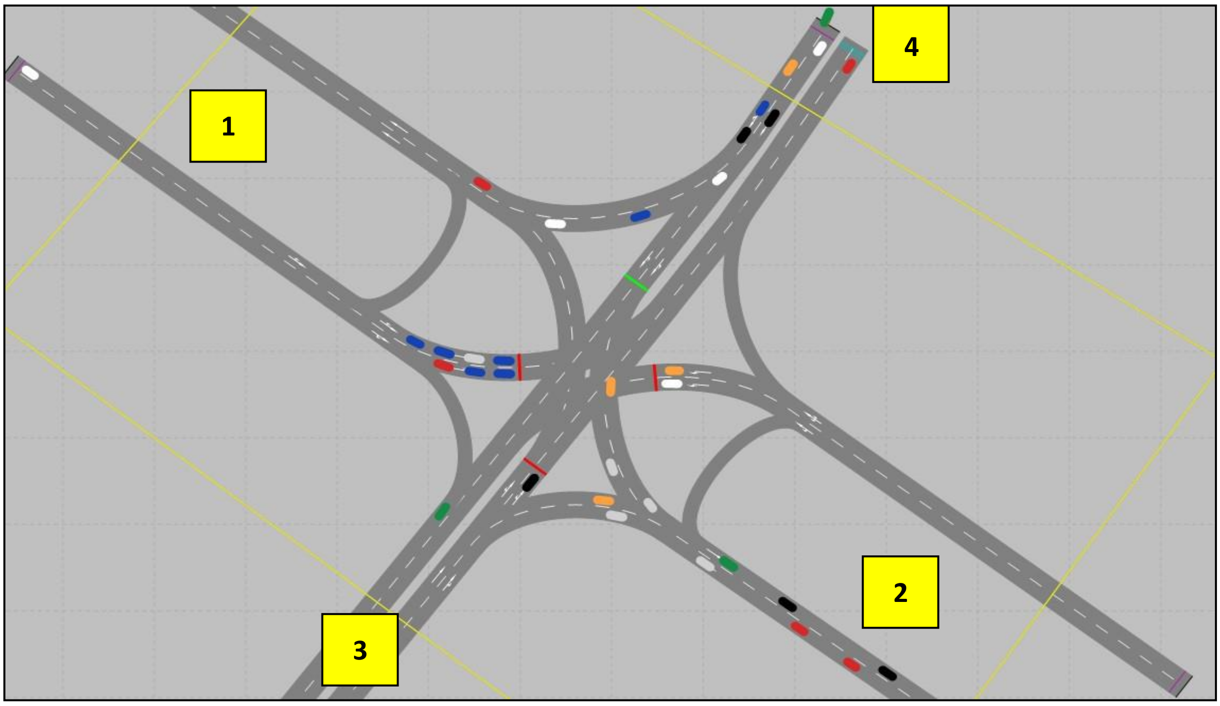

Figure 12. Two-dimensional image from the model established for the morning peak hour in the ALT - I scenario (1,500/3,600 seconds).

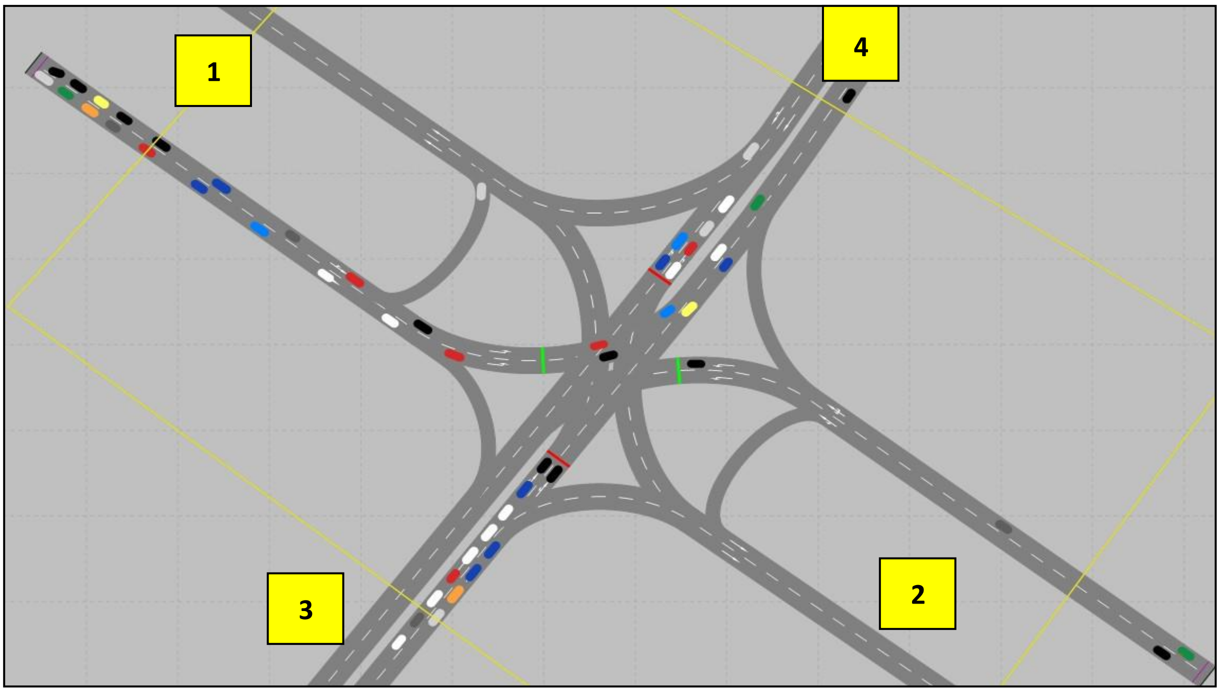

Figure 13. Two-dimensional image from the model established for the evening peak hour in the ALT - I scenario (1,500/3,600 seconds).

Following the studies conducted on the Junction 40 (Shell), issues were identified, and solutions proposed from a scientific perspective were tested within the model. The performance analyses of the alternative scenario were compared with the current state, calculating the improvement rates among the parameters. These values are provided in Table 9. The analysis of the junction's service level is presented in Table 10.

Table 9. Performance analysis of the Shell (Kalender) Intersection in the ALT - I scenario and improvement rates compared to the current situation

Parameter	**Current Situation**		**Alternative-I (Single Point/Double Lane)**		Improvement Rate	
	*M.P.T.**	*E.P.T.* **	*M.P.T.*	*E.P.T.*	*M.P.T.*	*E.P.T.*
Average Delay per Vehicle (Sec/Veh)	254	229	18	31	93%	86%
Average Stop Delay per Vehicle (Sec/Veh)	153	138	12	21	92%	85%
Average Number of Stops per Vehicle	5	5	1	1	90%	84%
Average Speed (Km/H)	5,60	6,46	18,32	19,05	227%	195%
Total Number of Stops	10.724	10.600	1.812	3.713	83%	65%

* *M.P.T. = Morning Peak Time*

** *E.P.T. = Evening Peak Time*

Table 10. Comparison of Service Levels for Alternative - I Scenario

	Current Situation		**Alternative – I**	
	Morning	Evening	Morning	Evening
Service Level	F	F	B	C

Accordingly, it has been determined that the new intersection design implemented in the ALT – I scenario for the Junction 40 (Shell) facilitates better traffic flow compared to the current situation. Additionally, with the new phase plans to be applied during peak hours in the new design, an improvement of 93% in the morning peak hour and 86% in the evening peak hour in average vehicle delay has been observed compared to the current state. Furthermore, an improvement in average speeds at the junction of 227% during the morning peak and 195% during the evening peak has been noted.

While the junction's service level exhibited "F" class performance during both morning and evening peak hours in the current state, the Alternative – I scenario shows the junction's service level improving to "B" during the morning peak and to "C" during the evening peak.

7.3. Analysis of Alternative-2 Scenario

Another alternative developed for the Junction 40 (Shell) is named ALT – II. In this alternative scenario for the junction, despite the physical provision of a 6-meter lane width on the side roads of the D-400

Highway, the inflexibility of physical constraints such as the overpass pillars has resulted in these roads continuing to operate as single lane one-way (1x1) as in the current state.

For the junction, which is currently operated with a flash signal plan, a "Single Point (Single Point)" junction design has been planned in the ALT – II scenario, with plans to operate the junction with a three-phase signal plan. Circuit diagrams planned for implementation at the junction under this scenario are provided in Figures 14 and 15. A cycle time of 80 seconds has been determined for the morning peak hour, while for the evening peak hour, this duration has been set at 82 seconds.

The phase plans anticipated for the morning and evening peak hours in the ALT – II scenario of the Junction 40 (Shell) are presented in Table 11. With the junction design determined to be Single Point, the junction, which previously operated with approach arms using a flash signal plan, has been transitioned to operate with a three-phase signal system.

Table 11. Predicted phase plan for the morning peak hour in Alternative – II scenario

ALTERNATİVE – II		**Phase Plan (Green Times)**			
		M.P.T.*	Period S.	E.P.T.**	Period S.
Junction 40 (Shell)	D/400-Adliye	20 sec.	80 sec.	24 sec.	82 sec.
	D/400-Gar	20 sec.		24 sec.	
	Olay TV	20 sec.		20 sec.	
	Ömer ERSOY	24 sec.		20 sec.	

* M.P.T. = Morning Peak Time

** E.P.T. = Evening Peak Time

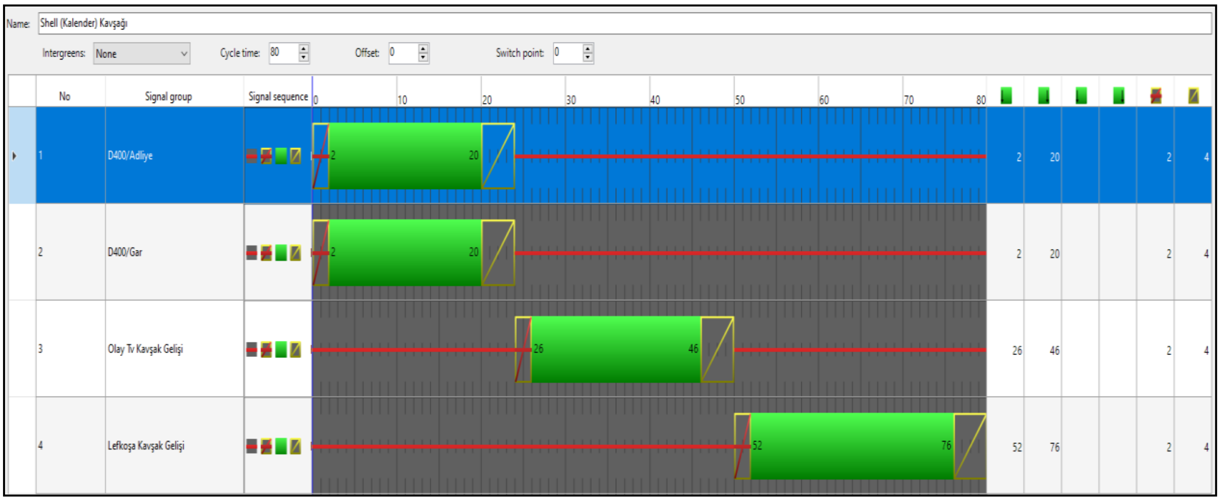

Figure 14. ALT - II scenario, the circuit diagram planned for the morning peak hour

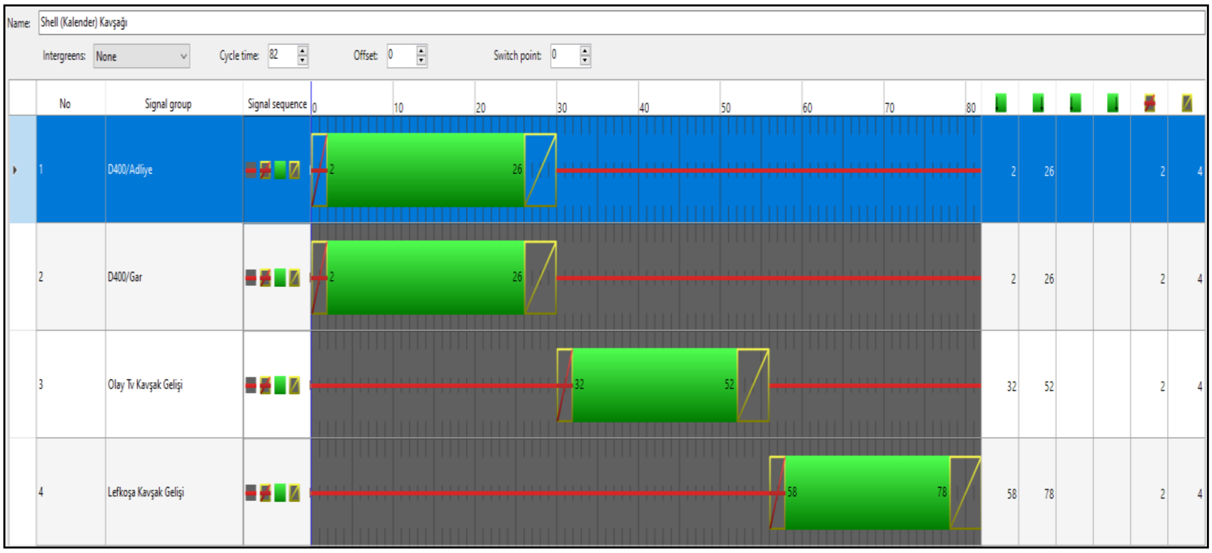

Figure 15. ALT - II scenario, the circuit diagram planned for the evening peak hour

The two-dimensional visuals for the morning and evening peak hours taken from the Alternative - II model are provided in Figure 16 and Figure 17.

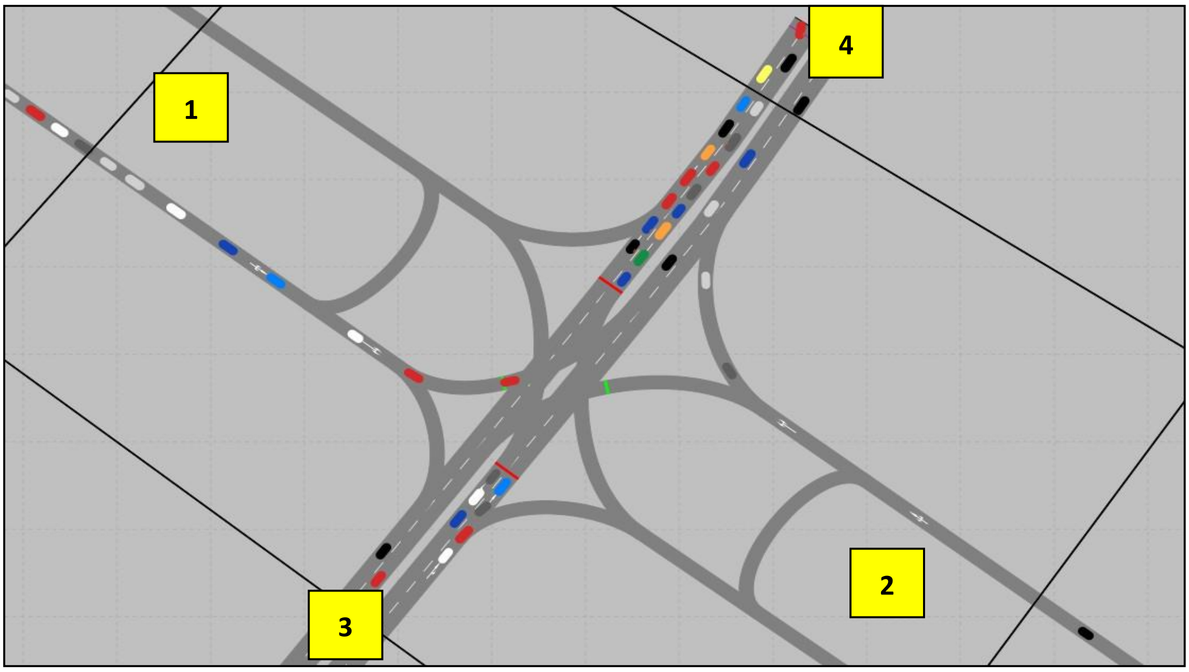

Figure 16. Two-dimensional image from the model established for the morning peak hour in the ALT - II scenario (1,500/3,600 seconds).

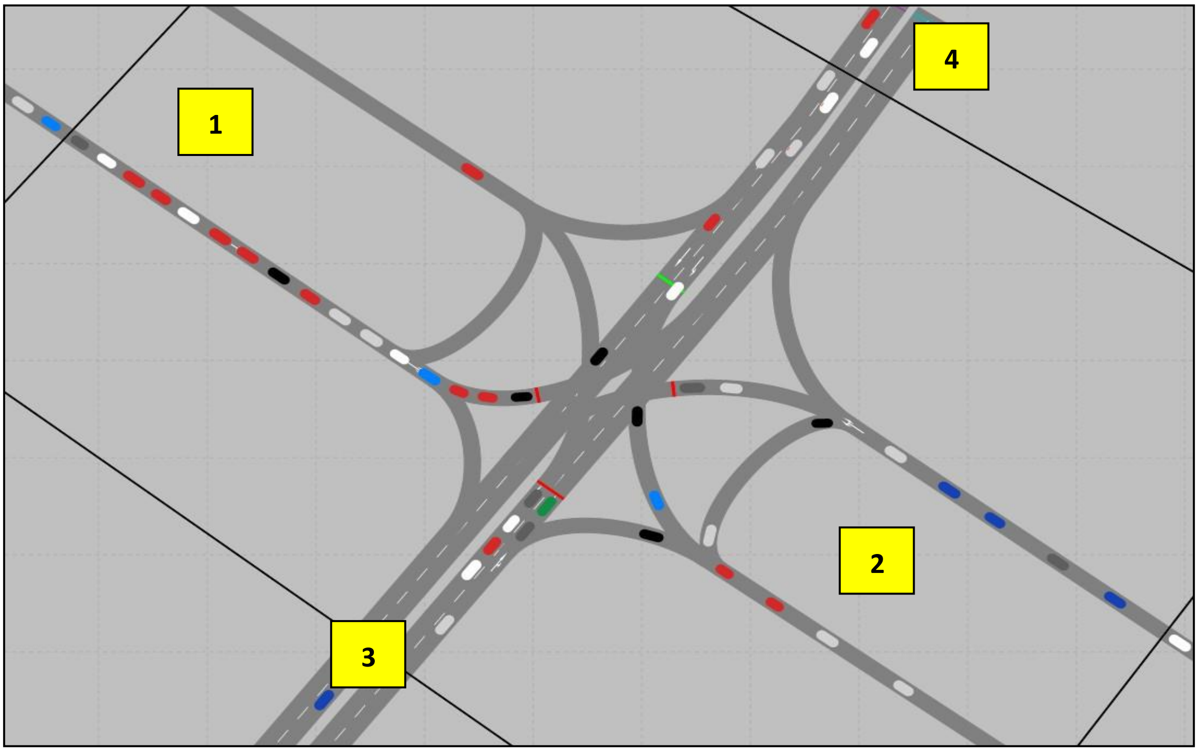

Figure 17. Two-dimensional image from the model established for the evening peak hour in the ALT - II scenario (1,500/3,600 seconds).

Following the investigations conducted at the Junction 40 (Shell), issues have been identified, and solutions proposed from a scientific perspective were tested within the model. The performance analyses of the alternative scenario were compared with the current situation to determine the rates of improvement across various parameters. These figures are provided in Table 12. The analysis of the junction's service levels is presented in Table 13.

Table 12. Performance analysis of the Junction 40 (Shell) in the ALT - II scenario and improvement rates compared to the current situation

Parameter	**Current Situation**		**Alternative-I (Single Point/Double Lane)**		Improvement Rate	
	*M.P.T.**	*E.P.T.* **	*M.P.T.* *	*E.P.T.* **	*M.P.T.* *	*E.P.T.* **
Average Delay per Vehicle (Sec/Veh)	254	229	31	30	88%	87%
Average Stop Delay per Vehicle (Sec/Veh)	153	138	21	20	86%	85%
Average Number of Stops per Vehicle	5	5	1	1	86%	84%
Average Speed (Km/H)	5,60	6,46	19,00	19,67	239%	204%
Total Number of Stops	10.724	10.600	2.376	3.119	78%	71%

* M.P.T. = Morning Peak Time

** E.P.T. = Evening Peak Time

Table 13. Comparison of Service Levels for Alternative - II Scenario

	Current Situation		**Alternative – II**	
	Morning	Evening	Morning	Evening
Service Level	F	F	C	C

Accordingly, for the Junction 40 (Shell), the new intersection design applied in the ALT – II scenario has been found to facilitate a better flow of traffic compared to the existing condition. Additionally, with the new design and phase plans implemented during peak hours, an improvement in the average delay per vehicle of 88% during the morning peak and 87% during the evening peak has been identified in comparison to the current state. Moreover, an improvement in average speeds at the junction has been observed, with an increase of 239% during the morning peak and 204% during the evening peak.

While the junction's service level displayed "F" class performance during both morning and evening peak hours in the current situation, in the Alternative – I scenario, the junction's service level improved to "C" during both peak periods.

8. Conclusion

Following the studies conducted at the Junction 40 (Shell), issues were identified, and solutions proposed from a scientific perspective were tested within the model. The performance analyses of the alternative scenario were compared with the current situation, and the rates of improvement among the parameters were calculated. These figures are provided in Table 14. The analysis of the junction's service levels is presented in Table 15.

Table 14. Performance analysis of the Junction 40 (Shell) in the ALT - II scenario and improvement rates compared to the current situation

Parameter	**Current Situation**		**Alternative-I (Single Point/Double Lane)**		Improvement Rate	
	*M.P.T.**	*E.P.T. ***	*M.P.T.* *	*E.P.T.* **	*M.P.T.* *	*E.P.T.* **
Average Delay per Vehicle (Sec/Veh)	254	229	31	30	88%	87%
Average Stop Delay per Vehicle (Sec/Veh)	153	138	21	20	86%	85%
Average Number of Stops per Vehicle	5	5	1	1	86%	84%
Average Speed (Km/H)	5,60	6,46	19,00	19,67	239%	204%
Total Number of Stops	10.724	10.600	2.376	3.119	78%	71%

* **M.P.T. = Morning Peak Time**

** **E.P.T. = Evening Peak Time**

Table 15. Comparison of Service Levels for Alternative - II Scenario

	Current Situation		**Alternative – II**	
	Morning	Evening	Morning	Evening
Service Level	F	F	C	C

Accordingly, The Alternative 1 scenario involves redesigning the intersection with a Single Point Urban Interchange (SPUI) design and utilizing dual-lane roads. This scenario achieved a reduction in average vehicle delay by 93% during morning peak hours and 86% during evening peak hours, while increasing average speeds by 227% and 195%, respectively. However, physical limitations and potential challenges during the construction process were considered in the implementation of this scenario.

The Alternative 2 scenario also adopts the Single Point Urban Interchange (SPUI) design but maintains single-lane side roads due to existing physical constraints. This scenario achieved a reduction in average vehicle delay by 88% during morning peak hours and 87% during evening peak hours, while increasing average speeds by 239% and 204%, respectively. The primary reasons for preferring Alternative 2 are as follows:

1. **Physical Limitations and Feasibility**: Alternative 2 offers a more feasible solution by considering existing physical constraints. Due to physical barriers such as the pillars of the overpass, it is not possible to convert the side roads to dual lanes. Therefore, a single-lane arrangement is considered a more realistic and feasible solution.
2. **Construction Process and Traffic Management**: Implementing Alternative 2 will result in less complexity and fewer disruptions to traffic flow during the construction process. This will allow for more effective management of the existing traffic in the area.
3. **Performance Improvements**: Alternative 2 provides performance improvements comparable to those of Alternative 1. The improvements in average vehicle delay and average speeds elevate the intersection's level of service to "C" and significantly enhance traffic flow.

In conclusion, the Alternative 2 scenario has been identified as a more suitable and feasible solution for optimizing traffic flow at the Shell Intersection. This study aims to contribute to the improvement of urban traffic management through the integration of intelligent transportation systems and geometric arrangements. Future studies may conduct more comprehensive analyses to evaluate the long-term effects of the proposed arrangements and investigate their applicability to similar intersections.

Proposals

The transition to the proposed Single Point intersection design as an alternative to the current state at the Junction 40 (Shell) could encounter the following issues:

The change in the junction design will initiate a construction process for a certain period, presenting a challenge for managing existing traffic flow.

Shell Petrol, located within the Zeytinli neighborhood and giving its name to the junction, may economically suffer from the fieldwork.

Aydemir Automotive, situated on the approach arm of the junction, could face inaccessibility to its entrance and exit points during the construction period.

Public transport vehicles using the junction will need alternative routes during construction. Although they can return to their original routes after construction, the route coded "S07" will need to utilize the underpass on the D/400 Highway for through passage.

Vehicles coming from the Courthouse or Küsget Industrial Site routes and using the junction to access Zeytinli or Mücahitler neighborhoods will have to extend their routes, performing a loop movement with the new junction design.

Researchers' Contribution Statement

All authors equally contributed to the study.

Acknowledgments and/or disclaimers,

Authors would like to extend their gratitude to the Gaziantep Metropolitan Municipality Transportation Department for providing data to be used throughout this study.

Conflict of Interest Statement,

There is no conflict of interest with any parties.

References

Akçelik, R. (2005) *Capacity and Performance Analysis of Roundabout Metering Signals*.

Akçelik, R. (2011) *An Assessment of the Highway Capacity Manual 2010 Roundabout Capacity Model*.

Akmaz. M., A. (2012) *Konyanın önemli sinyalize kavşaklarının bilgisayar programı ile incelenmesi*. Available at: https://atif.sobiad.com/index.jsp?modul=kullanici-ayrinti&username=Muhammet%20Mevl%C3%BCt%20AKMAZ&alan=fen.

Aktaş, Y., Aslan, H. and Pistil, F. (2017) 'Sinyalize Kavşaklarda Meydana Gelen Taşıt Gecikmelerinin VISSIM Simülasyon Modellenmesi', *5th International Symposium on Innovative Technologies in Engineering and Science 29-30 September 2017 (ISITES2017 Baku - Azerbaijan)* [Preprint]. Available at: https://isites.info/PastConferences/ISITES2017/ISITES2017/Allpapers/B8-ISITES2017ID71.htm.

Arabaci, E. *et al.* (2020) 'Sinyalize Kavşaklarda Bekleyen Taşıtların Çevresel Etkileri: Dört Fazlı Bir Kavşak Üzerinden Durum Değerlendirmesi', *Volume: 3, Issue: 2 229-240* [Preprint]. Available at: https://doi.org/10.31200/makuubd.570622.

Aydın, M.M., Aydoğdu, İ. and Yıldırım, M.S. (2022) 'Sinyalize kavşaklarda ülkelere göre gecikme ve kuyruk uzunluğu denklemleri geliştirilmesinin gerekliliği üzerine bir araştırma', *Gümüşhane Üniversitesi Fen Bilimleri Dergisi*, 12(2), pp. 597–613. Available at: https://doi.org/10.17714/gumusfenbil.997924.

Bas, F. *et al.* (2020) 'Kentiçi Kavşakların Mikrosimülasyon Yöntemiyle Modellenmesi: Erzurum İli Örneği', *European Journal of Science and Technology*, pp. 444–451. Available at: https://doi.org/10.31590/ejosat.araconf58.

Benekohal, R. and Treiterer, J. (1988) 'CARSIM. CAR-following model for SIMulation of traffic in normal and stop-and-go conditions', *Transportation Research Record*, pp. 99–111.

Boxill, S.A. and Yu, L. (2000) 'An evaluation of traffic simulation models for supporting its development', in. Available at: https://www.semanticscholar.org/paper/an-evaluation-of-traffic-simulation-models-for-its-boxill-yu/000c115d77f12a7976276bf314c9dc220961a6ab.

Cakici, Z. and Murat, Y. (2015) *Sinyalize Dönel Kavşakların Performanslarının Farklı Senaryolar Altında İncelenmesi*.

Çakıcı & Murat (2020) *Sinyalize kavşaklar için optimizasyon tabanlı trafik yönetim modeli | GCRIS Database | Pamukkale University*. Available at: https://gcris.pau.edu.tr/handle/11499/28648 (Accessed: 11 July 2024).

Çetin, M. (2015) *Sinyalize kavşaklarda doygun akım oranının belirlenmesinde yeni bir yaklaşım*. Doctoral Thesis. Pamukkale Üniversitesi. Available at: https://gcris.pau.edu.tr/handle/11499/50104.

Çetinkaya, G. (2008) 'Işıklı Kavşaklarda Değişik Hesaplama Yöntemlerinin Karşılaştırılması'. Available at: http://hdl.handle.net/11527/4881.

Fellendorf, M. and Vortisch, P. (2011) 'Microscopic traffic flow simulator VISSIM', in, pp. 63–93. Available at: https://doi.org/10.1007/978-1-4419-6142-6_2.

Gettman, D. (2003) 'Surrogate Safety Measures from Traffic Simulation Models', *Transportation Research Record*, 1840. Available at: https://doi.org/10.3141/1840-12.

Hoogendoorn, S. and Bovy, P. (2001) 'State-of-the-art of vehicular traffic flow modeling', *J. Syst. Cont. Eng.*, 215, pp. 283–303. Available at: https://doi.org/10.1243/0959651011541120.

Ilıcalı, M. and Saraç, S. (2019) 'Trafik Sıkışıklığının Azaltılmasında Ulaşım Çözümlerinin Etkisi', *Trafik ve Ulaşım Araştırmaları Dergisi*, 2, pp. 93–107. Available at: https://doi.org/10.38002/tuad.567060.

Mahmassani, H. (2001) 'Dynamic Network Traffic Assignment and Simulation Methodology for Advanced System Management Applications', *Networks and Spatial Economics*, 1, pp. 267–292. Available at: https://doi.org/10.1023/A:1012831808926.

Murat, Y. and Cakici, Z. (2017) *Sinyalize Kavşaklarda Durma Gecikmesi ve Kontrol Gecikmesi Arasındaki İlişkinin İncelenmesi*.

Özdirim, M. (1972) 'Türkiyede trafik sinyalizasyonunun formüle edilmesi'. Available at: http://hdl.handle.net/11527/16852.

Papageorgiou, M. *et al.* (2004) 'Review of road traffic control strategies', *Proceedings of the IEEE*, 91, pp. 2043–2067. Available at: https://doi.org/10.1109/JPROC.2003.819610.

Shahgholian, M. and Gharavian, D. (2018) 'Advanced Traffic Management Systems: An Overview and A Development Strategy'. arXiv. Available at: https://doi.org/10.48550/arXiv.1810.02530.

Simsir, F., Ozkaynak, E. and Ekmekci, D. (2013) *Kavşaklarda Trafik Sinyalizasyon Sisteminin Modellemesi ve Benzetimi*.

Sönmez, C. (2015) 'Sinyalize Kavşaklarda Trafik Akımının Modellenmesi'. Available at: http://hdl.handle.net/11527/10287.

Toğaç, M.G. (2023) 'Gaziantep İli Yapay Zeka Tabanlı Akıllı Ulaşım Sistemleri İle Adaftif Sinyalizasyon Kontrolü ve Simülasyonu', *2023* [Preprint].

TÜİK Kurumsal (2022). Available at: https://data.tuik.gov.tr/Bulten/Index?p=49685.

Webster, F.V. (1958) *Traffic Signal Settings*. H.M. Stationery Office.

Zeydan, Ö. *et al.* (2017) *SIDRA INTERSECTION Programı ile Kavşak İyileştirmesinin Taşıt Emisyon Miktarlarına Etkisi: Zonguldak Örneği*.

Ziboon, A.R.T (2019) *Traffic Performance Evaluation and Analyses of Al-Fallah Intersection in Baghdad City Utilizing SYNCHRO.10 Software*. Available at: https://www.researchgate.net/publication/337903601_Traffic_Performance_Evaluation_and_Analyses_of_Al-Fallah_Intersection_in_Baghdad_City_Utilizing_SYNCHRO10_Software.