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TRAFFIC SIMULATION OF A SIGNALIZED INTERSECTION DURING RUSH HOURS: A CASE STUDY

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Keywords

Traffic Signal, Simulation, Underpasses, Roundabouts

Abstract

This article focuses on simulating the traffic of one of the most crowded signalized intersections, the Vakıflar Intersection, in Izmir during rush hours. The main goals of this study are to examine the bottlenecks in the intersection and overcome the bottlenecks by proposing alternative solutions. A simulation model is generated and the results show that a significant number of vehicles are waiting in the eastbound and westbound directions of the intersection. To solve the problem, a new model with an underpass connecting the eastbound and westbound directions of the intersection is proposed. The results attained from the developed model have shown that the waiting time of the vehicles and the number of vehicles waiting in the queue on Şehitler Street and Kamil Tunca Boulevard have dramatically decreased.

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YOĞUN SAATLERDE SİNYALİZE BİR KAVŞAĞIN TRAFİK SİMÜLASYONU: BİR VAKA ÇALIŞMASI

Anahtar Kelimeler	Öz
Trafik Sinyali, Simülasyon, Alt Geçitler, Dönel Kavşaklar	*Bu çalışmada, İzmir'in en yoğun sinyalize kavşaklarından biri olan Vakıflar Kavşağının, trafiğin yoğun saatlerde simüle edilmesine odaklanılmıştır. Çalışma, kavşaktaki darboğazları daha iyi anlamak, analiz etmek ve iyileştirmek için çözümler önermek amacıyla ağ üzerindeki trafiği simüle etmek amacıyla yürütülmüştür. Simülasyon modeli ARENA Yazılımında oluşturulmuş ve ilk sonuçlar kavşağın doğu ve batı güzergahlarında önemli bir kuyruk problemi olduğunu göstermiştir. Sorunun üstesinden gelmek için kavşağın doğu ve batı taraflarını birbirine bağlayan bir alt geçit içeren yeni bir tasarım önerilmiştir. Geliştirilen modelden elde edilen sonuçlar, Şehitler Caddesi ve Kamil Tunca Bulvarı'nda kuyrukta bekleyen araç sayısının ve bekleme süresinin önemli ölçüde azaldığını göstermiştir.*

Araştırma Makalesi		Research Article	
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1. Introduction

Recently, traffic control and traffic optimization have attracted great interest from researchers due to the radical increase in vehicle usage all over the world. Increased usage of vehicles and traffic requires optimal control of traffic flow especially in urban areas. The optimization of traffic flow will help administrators for accommodating and handling high traffic volumes. Precisely, optimizing traffic flow would be important to reduce pollution, time, consumption, etc. Therefore, there is a need to decrease traffic congestion on roads and intersections considering the safety of drivers and other passengers including pedestrians.

Traffic congestion causes delays, reduced flow speeds, and higher fuel consumption, leading to negative environmental impacts. Various models can represent traffic congestion and flows, depending on different assumptions. Van Woensel and Vandaele (2007) classified these models into interrupted and uninterrupted flows. Interrupted flow is controlled externally through measures like traffic lights or traffic police, while uninterrupted flow encompasses interactions solely between vehicles, both in terms of vehicle-to-vehicle and the interactions among vehicles traveling on a roadway.

In this study, the interrupted flow in an intersection in the third most crowded city of Turkey is taken into consideration. The main roads constructing this intersection are called Şehitler Street, Kamil Tunca Boulevard, and Fatih Street. In this junction, which is called Vakıflar Junction, traffic flow is controlled by periodic traffic signals. The fixed-cycle traffic light control system exemplifies interrupted traffic flow. In this scenario, vehicles approach an intersection governed by traffic lights, which alternate between green and red phases. Vehicles delayed within the intersection are expected to clear out during the green light intervals at consistent time intervals.

Various analyses have been conducted regarding the arrival processes of vehicles during the 2-hour rush hour period in the morning. According to the provided data, vehicles are categorized into three types: passenger cars, buses, and minibusses. It's worth noting that the data provided by the Izmir Traffic Department are in absolute numbers, not percentages, detailing the count of vehicles arriving from and departing in different directions. The interarrival time of vehicles from each direction is assumed to follow a random exponential distribution, contingent upon the hourly traffic volumes. Further details regarding the distribution fitting details of the model are given in subsequent sections of the article.

When the goal is to reduce expenses, the significance of optimization approaches becomes paramount. Globally, numerous expensive projects have been undertaken to enhance traffic flow, but the anticipated results have not been achieved. Hence, this study focused on addressing a local traffic flow issue at an intersection by identifying its root causes and proposing solutions without incurring significant operational expenses.

Considering the operational expenses of the projects, it is not logical to apply them in the real world without simulating the situation. In recent years, there have been many simulation software to be used in different realms of study. In this study, the selection of ARENA Software was based on its ability to simulate a variety of research scenarios. ARENA is also such versatile software that can be used in other areas.

1.1. Motivation of the Study

The motivation for this research comes from the need to improve the traffic congestion that happens in one of the most crowded parts of Izmir. Since Vakıflar Junction is in Alsancak which is very close to the city center of Izmir, most students and workers are obliged to pass through this junction between 7:30 a.m. to 9:30 a.m. During these rush hours, it is easy to observe the traffic congestion in Vakıflar Intersection which is controlled by traffic signals. Due to this congestion in the area, people get bored of getting stuck in the traffic. Through any improvement made in this junction, drivers will be more satisfied and there will be a decrease in the waiting times in the queues on roads.

This study also takes its motivation from the wide usage of ARENA Software to simulate the situation of the Vakıflar Intersection. It is a good opportunity to develop a simulation model to check the current system and then improve it using simulation software before the actual construction takes place.

1.2. Study Objectives

The study aims to achieve the following objectives:

- Simulate network traffic to gain a comprehensive understanding and analyze the problem.
- Determine waiting times in queues to enhance driver and passenger satisfaction.
- Evaluate the effectiveness of the existing system through data obtained from simulations.
- Identify weaknesses in the current system and explore potential improvement strategies.
- Investigate the impact of modifications on the existing system to enhance its efficiency.
- Propose innovative solutions to enhance the system's effectiveness and overall performance.
- Demonstrate the utilization of ARENA for analyzing the microscopic behaviors within traffic scenarios.

2. Literature Review

Lately, tackling the problems related to traffic flow has been receiving considerable attention. According to Sheu (2006), this is because the huge number of vehicles creates various problems such as traffic jams, air pollution, waste of fuel, etc. Simulation approaches have become very common and significant methods in order to analyze traffic networks and mitigate the pertaining problems. Complexity of the traffic systems also increases the requirement of analyzing traffic control. Another consideration in the traffic discipline is the selection of the appropriate software in order that some organizations can conduct research for selection of their simulation software. For instance, Otamendi, Pastor and Garcı (2008) conducted a research for an international airport in Spain whether to choose between Arena or Witness as their simulation platform by using AHP.

The advancement of Traffic Signal Control (TSC) systems has been critical in urban traffic management, with continuous enhancements since the introduction of the automatic signal controller to alleviate congestion factors (Zhao, Dai and Zhang, 2011). Notably, foundational work by Webster (1958) established guidelines for minimizing average delay, which later influenced the development of the TRANSYT tool by Robertson (1969) for optimizing Traffic Signal Timing (TST). This was furthered by contributions from Allsop (1972) and Akcelik (1981), who refined the modeling of intersection capacity and delays, integrating factors such as the average number of stops into the Australian Road Research Board (ARRB) TST method.

Subsequent studies have been bifurcated into two distinct categories: microsimulation-based optimization (SimOpt) models and computational intelligence (CI)-based models. SimOpt models, as described by Carson and Maria (1997), employ simulation analysis to discern the best decision variable values among a multitude of possibilities without the need for exhaustive evaluation. This approach is exemplified in the work by Spall and Chin (1997), where traffic data are used to calculate optimum traffic signal times without relying on established mathematical models.

In the realm of CI-based models, a variety of techniques including machine learning, fuzzy logic, and evolutionary computation (EC) have been harnessed (Venayagamoorthy, 2009). The CI methods are adept at finding near-optimal solutions to complex, nonlinear problems (Eiben and Smith, 2015) and have been integrated with traffic simulation tools for enhanced evaluation of TSC systems.

The AI-based approaches within CI models have pioneered the use of nature-inspired algorithms, like the cuckoo search algorithm by Araghi, Khosravi and Creighton (2015), which tuned intelligent controllers such as Neural Networks (NN) and Adaptive Neuro-Fuzzy Inference Systems (ANFIS), with evaluation done via Paramics. Jin, Ma and Kosonen (2017) developed a fuzzy logic-based intelligent control system for TST, assessed using SUMO, reflecting the potency of AI in managing isolated traffic intersections.

Meta-heuristics have also played a pivotal role in TST optimization, addressing the multi-objective and dynamic nature of traffic networks. Genetic Algorithms (GA), Particle Swarm Optimization (PSO), and other population-based algorithms have been used to navigate the solution space effectively (Gökçe, Öner ve Işık, 2015; Dabiri and Abbas, 2016). The integration of these algorithms with microsimulation tools, as demonstrated by Miletić, Kapusta and Ivanjko (2018) and others, has significantly reduced vehicular waiting times and improved traffic flow. Notably, multi-objective optimization techniques, such as the NSGA-II algorithm (Nguyen, Passow and Yang, 2016), have facilitated the simultaneous optimization of multiple TST objectives, proving superior to single-objective approaches. Additionally, bi-level programming methods have been applied for concurrent TST optimization and traffic assignment (Hajbabaie and Benekohal, 2015).

In terms of dynamic and real-time TST strategies, MILP-based models and approaches employing real-time data have emerged (Chen and Sun, 2016; Köhler and Strehler, 2019). These are geared towards optimizing TST in response to current traffic conditions, marking a significant leap from static models to adaptable traffic systems. Miscellaneous approaches have also been reported, such as the employment of game theory for decentralized cycle-free TST (Abdelghaffar, Yang and Rakha, 2017) and the use of condensed nearest neighbor algorithms for signal control (Louati, Elkosantini, Darmoul and Ben Said, 2019). Additionally, the application of fog computing for non-centralized TSC highlights the innovative edge of current research (Tang, Xia, Zhu and Wei, 2019).

The literature suggests an emerging trend towards hybrid algorithms that blend multiple computational strategies to enhance TST optimization. Such hybridization aims to reduce complexity and increase efficiency, as indicated by the work of Li & Schonfeld (2015). Overall, the field is progressing towards algorithms that can effectively reduce congestion, improve traffic flow, and are verified by simulation tools like PTV VISSIM (Murat, Cakici and Tian, 2019), showcasing the practical application of these research advancements.

Qadri, Gökçe and Öner (2020) provides a summary of recent literature between 2015 and 2020 concerning simulation-optimization and computational intelligence based approaches for optimizing traffic signal control systems. In more recent studies, Stupin, Kazakovtsev and Stupina (2022) studies modernizing city roundabouts and explores options such as integrating traffic lights into existing roundabouts and proposing upgrades for increased capacity. Mok ve Zhang (2024) proposes a signal control approach that integrates deep learning and simulation. They demonstrate significant improvements in traffic efficiency through experimental validation.

3. Case Study Description

This study concentrates on simulating traffic at the Vakıflar intersection in Izmir, the third most populous city in Turkey. This intersection is monitored between 7:30 a.m. and 9:30 a.m., during rush hours when people go to either work or school.

This junction consists of controlled intersections, characterized by the presence of traffic lights. The fixed-cycle traffic light system exemplifies interrupted traffic flow; at these intersections, vehicles are governed by alternating green and red-light phases. The duration of these phases can vary for traffic coming from different directions. Due to higher traffic density from the west to the east, the green light phase is extended compared to other directions to prevent congestion.

Referring to Figure 1, the primary roads at the junction are named Kamil Tunca and Şehitler. If no traffic lights were controlling the junction, it would be logical for vehicles on the main road to have priority. Given this, we can infer that the main road runs from west to east or vice versa.

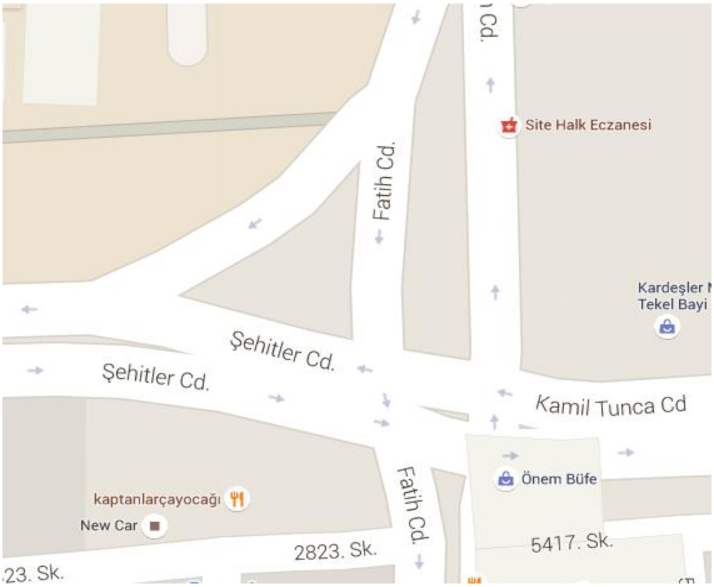


Figure 1. Traffic Flow Between the Junctions

The issues at the mentioned intersection can be categorized into two main concerns: firstly, the level of service it offers to drivers and passengers, and secondly, the safety of both drivers and pedestrians utilizing this junction.

In this study, since it is focused on only rush hour traffic, we are given some data showing how many passenger cars, busses and minibuses have passed through this junction from each direction to other directions. These data will be beneficial in developing a current model and improved version of the system.

At the intersection, queues often form in the south and north directions due to the extended green light period for vehicles coming from the east and west directions. This situation results in a growing number of vehicles waiting in line. From the data provided, it's evident that the queue length correlates with the traffic volume. As our data focuses on rush hour periods, the problem intensifies during peak times like these. Consequently, drivers in each direction may likely become frustrated by these prolonged wait times.

Furthermore, intersections—particularly those without traffic signals—always present potential hazards. Given the high traffic volume on Şehitler Street and Kamil Tunca Boulevard, drivers on these routes tend to travel at relatively high speeds. Motorists approaching from either side of Fatih Street often find themselves stopping more frequently, even when there's no oncoming traffic from the west and east directions. The degree of danger also correlates with drivers' risk-taking tendencies. Those exhibiting riskier driving behaviors often maintain shorter safe distances from vehicles on the main road, thereby heightening the danger at intersections. Conversely, more cautious drivers, while reducing risk, can contribute to longer queue lengths.

4. Model Development

The above mentioned system is simulated in Arena software to analyze some important outputs such as waiting times, queue lengths in each direction and the frequency of vehicles passing through Vakıflar Junction during rush hours. In the following, the model assumptions and elements on which it has been based will be discussed.

The model has been constructed based on the following assumptions:

- **No jockeying allowed in the system:** This implies that once vehicles are in a queue, they cannot change lanes or positions within that queue to potentially move faster. This is important for simplification because lane-changing behaviour can significantly complicate the simulation and the flow dynamics.
- **Vehicles do not leave the system after entering the queues:** Once vehicles enter the queue at the junction, they stay in the queue until they pass through the junction. This means the model does not account for drivers who might choose alternative routes or exit the queue prematurely for any reason.
- **No vehicle stops unless the junction is occupied:** Vehicles are assumed to continue moving unless they reach a point where they cannot progress due to the junction being full or traffic signals instructing them to stop. This simplifies the traffic flow by assuming it's either moving or halted by the junction, with no intermediate stopping points.
- **No interruption occurs to the traffic flow because of accidents and breakdowns:** The simulation assumes ideal conditions where incidents such as accidents or vehicle breakdowns that can block traffic flow do not occur. This removes the variability and unpredictability these events would introduce into the model.

- **The length of each vehicle is not ignored:** The model takes into account the size of vehicles, acknowledging that different vehicles occupy varying amounts of space in a queue. This ensures more accurate calculations regarding queue length and vehicle accumulation, reflecting the realistic variability in vehicle sizes.
- **There are two adjacent lanes for each direction:** There are no separate lines. This assumption implies a single queue for all directions at the junction.

Overall, these assumptions are likely made to simplify the simulation model in Arena software, allowing for clearer analysis of key performance indicators like waiting times and queue lengths, without the additional complexity that more nuanced modelling would require. However, they also limit the model's ability to capture the full complexity of traffic behaviour at the Vakıflar Junction during rush hours. This study complied with research and publication ethics.

4.1. Data Collection

In order to simulate the current system in ARENA software, all data were gathered between 7:30 am – 9:30 am, a period identified as the rush hours of the intersection based on observations. Solving the problem during this timeframe aims to comprehensively address the network issue. Data collection lasted until one hundred observations were collected. The Input Analyzer tool in Arena was employed for distribution fitting. Further details regarding the data and distribution fitting are presented in Table 1. According to the distribution fitting, the approximate interarrival times are summarized in Table 2.

Also, there are different types of vehicles such as passenger cars, buses, and minibuses using this junction during the day. We used ratio 1 and ratio 2 values to separate vehicle types for each route in our simulation model. These ratios are calculated based on the collected data. Table 3 shows ratio 1 and ratio 2 values for time frames 7:30 am – 8:30 am and 8:30 am – 9:30 am and each vehicle type.

Table 1.
Details of the Distribution Fitting of the Collected Data

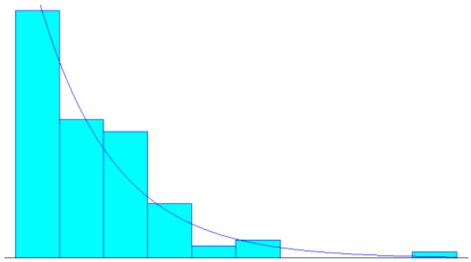
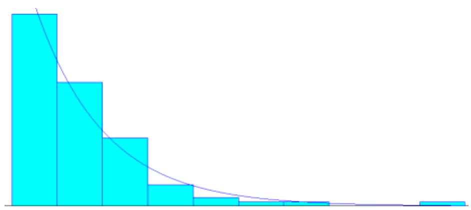
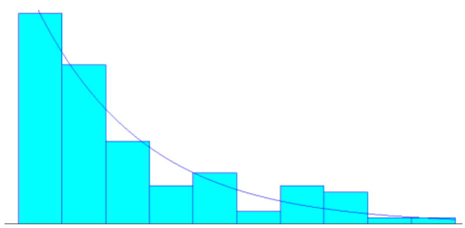
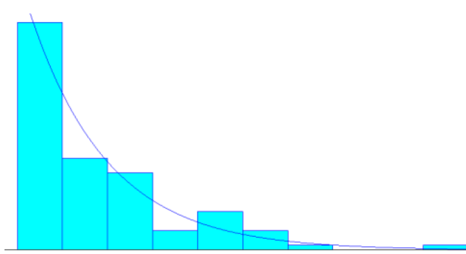
Distribution: EXPO(5.15) Square Error: 0.007555 Number of Data Points = 100 Chi Square Test Number of intervals = 4 Degrees of freedom = 2 Test Statistic = 4.48 Corresponding p-value = 0.11 Kolmogorov-Smirnov Test Test Statistic = 0.0585 Corresponding p-value > 0.15	
Distribution: EXPO(3.66) Square Error: 0.004218 Number of Data Points = 100 Chi Square Test Number of intervals = 4 Degrees of freedom = 2 Test Statistic = 3.64 Corresponding p-value = 0.179 Kolmogorov-Smirnov Test Test Statistic = 0.0665 Corresponding p-value > 0.15	
Distribution: EXPO(3.23) Square Error: 0.005297 Number of Data Points = 100 Chi Square Test Number of intervals = 5 Degrees of freedom = 3 Test Statistic = 2.98 Corresponding p-value = 0.412 Kolmogorov-Smirnov Test Test Statistic = 0.0598 Corresponding p-value > 0.15	
Distribution: EXPO(2.95) Square Error: 0.007799 Number of Data Points = 100 Chi Square Test Number of intervals = 4 Degrees of freedom = 2 Test Statistic = 1.87 Corresponding p-value = 0.412 Kolmogorov-Smirnov Test Test Statistic = 0.0568 Corresponding p-value > 0.15	

Table 2.
Time Between Arrivals

	Type	Value (seconds)
Fatih from South	Random (Expo)	5.15
Fatih from North	Random (Expo)	3.66
From Şehitler (West)	Random (Expo)	3.23
From Kamil Tunca (East)	Random (Expo)	2.95

Table 3.
Percentages of Vehicle Types Arriving at the Intersection

		7:30 am - 8:30 am Percentage 1	8:30 am - 9:30 am Percentage 2
Fatih from South	Car	89%	91%
	Bus	6%	5%
	Minibus	5%	4%
	Total	100%	100%
Fatih from North	Car	89%	90%
	Bus	5%	4%
	Minibus	6%	5%
	Total	100%	100%
From Şehitler (West)	Car	91%	90%
	Bus	4%	5%
	Minibus	5%	5%
	Total	100%	100%
From Kamil Tunca (East)	Car	92%	91%
	Bus	2%	2%
	Minibus	6%	6%
	Total	100%	100%

4.2. Simulation Duration and Replication Count

Initially, the system starts empty, meaning no vehicles are present in the model, and all resources are idle. This situation does not reflect real-world conditions accurately, as systems are rarely empty. Therefore, the analysis focuses on results after the system achieves a stable state. To identify this, a stable output of the system is selected to determine the warm-up period. The model was initially executed for 2 hours with 5 replications. Calculating the warm-up period was not possible due to insufficient data for plotting. According to Table 4, it can be concluded that the average waiting time in each direction does not change significantly when the number of replications changes.

To demonstrate the adequacy of the replication number and the smallness of the deviation, it is shown that a small number of replications is sufficient. This is explained through the utilization of the following formula:

$$N_m = \left(\frac{S_m \times t_{m-1,1-\frac{\alpha}{2}}}{\bar{X}_m \times \epsilon}\right)^2 \quad (1)$$

where N_m is the number of replications, S_m is the data standard deviation, $t_{m-1,1-\frac{\alpha}{2}}$ is the test statistic obtained from t-table, m is the number of initial replications that was assumed to be 5, $1-\alpha$ is the confidence interval as 95%, $\bar{X}_m$ is the data mean and ϵ is the allowable percentage error. The allowable error percentage of 5% with $t_{m-1,1-\frac{\alpha}{2}}$ equals 2.776. When the calculation is made based on the above formula for arrivals from each direction, the value of N_m, which is the necessary number of replications, is obtained as given in Table 4. Consequently, since 5 replications exceed all the calculated necessary replications, it confirms that 5 replications were already sufficient to get accurate results.

Table 4.
Initial Replication Results: Average Waiting Times in Queue

	R1	R2	R3	R4	R5	Avg.	Std. Dev.	N_m
Fatih from South	32.04	32.01	31.80	31.73	32.25	31.96	0.21	0.13
Fatih from North	29.02	29.10	29.35	28.05	28.84	28.87	0.50	0.91
From Şehitler (West)	16.79	16.30	16.12	16.45	16.24	16.38	0.26	0.76
From Kamil Tunca (East)	19.72	19.28	19.46	20.26	20.04	19.75	0.40	1.29

4.3. The Current System

In the current system, four entry routes form the Vakıflar Intersection in the system: vehicles arrive from Şehitler, Kamil Tunca, and Fatih (from north and south) streets. In order to make our system much more visible, Figure 2 is used to show the flow of the current system which includes vehicle arrival from south on Fatih Street.

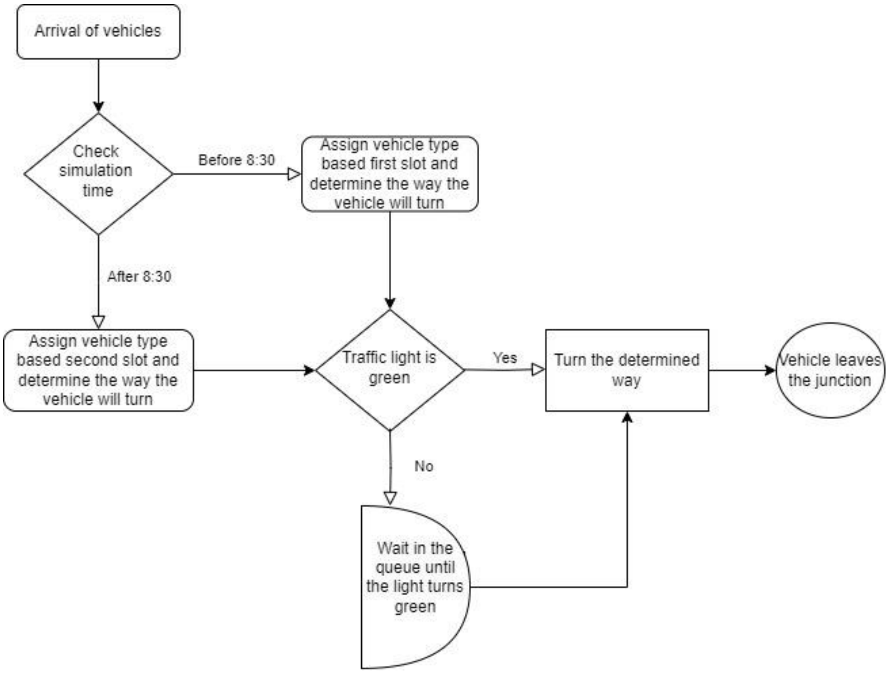


Figure 2. Flow Chart of the Current Situation of Vakıflar Intersection

In the system, there are three different types of vehicles passing through this junction. These are passenger cars, buses, and minibusses. To differentiate the type of vehicles, we have used the ratios that we calculated as given in Table 3. Before using these ratios in the Decide module in ARENA, we used the TNOW function which keeps the simulation time to differentiate the ratios for different rush hour times. As seen in Table 1, the ratios for types of vehicles coming from each direction alter according to time. For example, between 7:30 and 8:30, passenger cars compose %89 of the total vehicles coming from the south direction, whereas this ratio changes to %91 between 8:30 and 9:30.

Since the intersection is signalized, we require an additional entity that helps alter traffic light from green to red or red to green. Before the creation of this ghost entity, we measured the length of the green light of the junction for each direction. Since the traffic volume is very high between the west and east directions, we foresaw that the length of green lights in the west and east directions would be longer than the south and north directions. After watching the provided videos, we found out that green light lengths are 11, 15, 32, and 27 seconds for south, north, west, and east directions, respectively. We used the assign module to assign a number for each change in traffic lights and the delay module to represent the length of the green light. Delay modules provide the time when the vehicles are stopped.

In our model development section, we explained how Hold modules assess whether vehicles are passing through the junction. If the traffic light is red for vehicles approaching from a specific direction, drivers must wait until the light turns green. In the model, parallel to the Hold modules (queues), there is a pathway for vehicles to directly cross the junction when the traffic light is green. A Hold module is necessary to maintain vehicles in the queue. The Hold module checks if the condition light==1. When the "light" value equals 1, vehicles from the south direction are released into the system from the Hold module, while vehicles from other directions remain at their respective Hold modules. The variable "light" can only have values of 1, 2, 3, and 4.

After running the simulation model, the average number of vehicles leaving the system is calculated as 7997 vehicles in two hours. According to the data we are given, the average number of vehicles leaving the system in these two hours was 7901 vehicles. The calculations are given in Table 5. Therefore, we could conclude that our model is working well and accurately. According to Table 5, it can be seen that the total numbers of each type of vehicle are close to the true corresponding values that we are given. This also leads to the fact that our simulation model can represent the real system well.

Table 5.
Number of Each Type of Vehicles Leaving the System and Simulation

	In System	Simulation
Car	7155	7211
Bus	303	307
Minibus	443	479
Total	7901	7997

In order to compare the current system with the developed one, it is necessary to provide some statistical data obtained by ARENA such as average waiting time, number of vehicles waiting in the queue, and the maximum number of vehicles waiting in the queue, given in Table 6. Any increase or decrease in waiting time will lead us to conclude whether the proposed model works well or not. According to Table 6, it is easy to detect that the number of vehicles waiting in the south and north directions is too many to congest the traffic of the junction. Therefore, the new proposed model should aim at decreasing the number of vehicles in both queues.

Table 6.
Average Waiting Times and Number of Vehicles in the Queues of the Current Model

	Waiting time (in seconds)	*Number waiting / Max value*
Fatih from South	32.04	6.21 / 24
Fatih from North	29.02	7.65 / 32
From Şehitler (West)	16.79	5.15 / 29
From Kamil Tunca (East)	19.72	6.78 / 29

Vehicle size measurements have been determined based on the study conducted by Elefteriadou (2014), indicating dimensions of 4.27 meters (14 feet) for a car, 10.68 meters (35 feet) for a minibus, and 12.20 meters (40 feet) for a bus. Road widths and lane specifications have been ascertained through a comprehensive analysis of maps and literature that each lane spans approximately 6 meters in width, and each direction comprises two lanes. Further elaboration, including details and observed queue lengths categorized by vehicle types, can be found in Tables 7a and 7b. In addition, it is pertinent to note that during rush hours, the observed queue lengths tend to be significantly higher, indicating potential congestion and traffic challenges.

The average values of the directions to which vehicles approaching the Vakıflar intersection from all directions will turn are also shown in Tables 8a and 8b. Based on these average calculations, percentiles are computed, and direction selection is implemented in our simulation model.

Lastly, we decided to make use of the animation of ARENA software to visualize the current system. In order to animate the system in ARENA, it is required to add Route and Station modules to the simulation model. According to our observations, we estimated the time for each vehicle to pass the junction as 5 seconds and 15 seconds for vehicles to arrive at the junction from the starting point. Finally, to model the departure of vehicles from the system, a Dispose module serves as the exit point for all vehicles.

Table 7a.
Average Queue Lengths for Each Vehicle Type for the Current Model Between 7:30 am - 8:30 am

		7:30 am – 8:30 am Number waiting	7:30 am – 8:30 am Waiting per lane	7:30 am – 8:30 am Length per lane (meters)
Fatih from South	Car	5.53	2.76	11.80
	Bus	0.37	0.19	2.27
	Minibus	0.31	0.16	1.66
	Total	6.21	3.11	15.73
Fatih from North	Car	6.81	3.40	14.54
	Bus	0.38	0.19	2.33
	Minibus	0.46	0.23	2.45
	Total	7.65	3.83	19.32
From Şehitler (West)	Car	4.69	2.34	10.01
	Bus	0.21	0.10	1.26
	Minibus	0.26	0.13	1.38
	Total	5.15	2.58	12.64
From Kamil Tunca (East)	Car	6.24	3.12	13.32
	Bus	0.14	0.07	0.83
	Minibus	0.41	0.20	2.17
	Total	6.78	3.39	16.31

Table 7b.
Average Queue Lengths for Each Vehicle Type for the Current Model Between 8:30 am - 9:30 am

		8:30 am – 9:30 am Number waiting	8:30 am – 9:30 am Waiting per lane	8:30 am – 9:30 am Length per lane (meters)
Fatih from South	Car	5.65	2.83	12.07
	Bus	0.31	0.16	1.89
	Minibus	0.25	0.12	1.33
	Total	6.21	3.11	15.28
Fatih from North	Car	6.89	3.44	14.70
	Bus	0.31	0.15	1.87
	Minibus	0.38	0.19	2.04
	Total	7.65	3.83	18.61
From Şehitler (West)	Car	4.64	2.32	9.90
	Bus	0.26	0.13	1.57
	Minibus	0.26	0.13	1.38
	Total	5.15	2.58	12.84
From Kamil Tunca (East)	Car	6.17	3.08	13.17
	Bus	0.14	0.07	0.83
	Minibus	0.41	0.20	2.17
	Total	6.78	3.39	16.17

Table 8a.
Total Number of Vehicles from One Direction to Other Ones Between 7:30 am - 8:30 am

		7:30-8:30	East	North	West
Fatih from South	Car	579	50	411	118
	Bus	36	2	20	14
	Minibus	34	10	24	0
	Total	649	62	455	132
		7:30-8:30	East	South	West
Fatih from North	Car	863	133	558	172
	Bus	46	0	24	22
	Minibus	62	24	28	10
	Total	971	157	610	204
		7:30-8:30	East	South	North
From Şehitler (West)	Car	1014	734	55	225
	Bus	46	22	10	14
	Minibus	53	42	0	11
	Total	1113	798	65	250
		7:30-8:30	West	South	North
From Kamil Tunca (East)	Car	1107	796	94	217
	Bus	19	18	0	1
	Minibus	76	38	20	18
	Total	1202	852	114	236

Table 8b.
Total Number of Vehicles from One Direction to Other Ones Between 8:30 am - 9:30 am

		8:30-9:30	East	North	West
Fatih from South	Car	632	38	392	202
	Bus	37	3	22	12
	Minibus	29	6	23	0
	Total	698	47	437	214
		8:30-9:30	East	South	West
Fatih from North	Car	890	160	506	224
	Bus	40	0	18	22
	Minibus	54	17	26	11
	Total	984	177	550	257
		8:30-9:30	East	South	North
From Şehitler (West)	Car	956	570	113	273
	Bus	52	20	8	24
	Minibus	57	48	0	9
	Total	1065	638	121	306
		8:30-9:30	West	South	North
From Kamil Tunca (East)	Car	1114	790	109	215
	Bus	27	26	0	1
	Minibus	78	50	15	13
	Total	1219	866	124	229

5. Proposed Improvements

5.1. Propose an Underpass

In order to tackle the mentioned situation, an underpass for vehicles coming from the east and west directions is proposed. Since the traffic volume in the east and west directions is high, it would be a good idea to eliminate the vehicles going east from west and west from east in the junction. Therefore, the proposed underpass is supposed to be used only by vehicles moving through east and west directions. In other words, if a vehicle goes to either the south or north direction from either the west or east direction, this vehicle is supposed to join the junction and wait for the traffic lights to alter to green to move. But other vehicles can use this underpass to go to either the west or east direction.

Using this underpass decreasing the volume of vehicles through east and west directions, we provided an unsignalized and comfortable way for this big part of the vehicles.

As demonstrated in Tables 8a and 8b, it is easy to see that most of the vehicles in the system are going from east to west or west to east. Consequently, it is thought to construct an underpass through the west and east direction with two lanes. Construction of this underpass which enables vehicles to pass the junction without stopping because of traffic lights will help to decrease the number of vehicles waiting in the queue. Moreover, it is expected to see a dramatic decrease in the congestion of traffic and an increase in the satisfaction of the drivers.

To apply this change to our simulation model, we have eliminated "Hold" modules that seize the vehicles coming from east and west directions individually. Regardless of which direction the vehicles are directed, these hold modules seize all types of vehicles when the traffic light is red for the corresponding direction. But in our proposed case, vehicles from east to west and west to east are not supposed to be seized by these Hold modules since these vehicles will make use of the constructed underpass. Because of this situation, we eliminated these main hold modules and added two new hold modules that seize the vehicles from east and west directions to south or north ones. In other words, vehicles from east and west directions are not supposed to join the junction and wait for traffic lights to alter to green, as long as they do not go to either south or north directions.

When focused on the junction in the proposed improvement model, it can be seen that the volume has shifted from west and east to north and south directions. Because most of the vehicles coming from east or west directions have used the underpass without joining the junction. Therefore, the green light length for vehicles coming from north and south directions should be lengthened.

In the current model, it has already been found that green light lengths are 11, 15, 32, and 27 seconds for south, north, west, and east directions, respectively. When we used these values for the proposed model, we realized that the total number of vehicles has decreased instead of increasing. This decrease occurred because of the shift in volume to the north and south direction. In the proposed case, the volume of vehicles coming to the junction from the south and north directions is higher than the volume of the vehicles coming from the east and west directions. Therefore, lengths of 11 and 15 seconds for green lights in the south and north directions are not sufficient to let enough vehicles pass the junction in one cycle. It is required to increase the green light length for vehicles coming from these directions and decrease the same length for vehicles coming from west and east directions. If we do not decrease the green light length for east and west directions, the junction will remain empty after all vehicles in these directions pass through the junction and the traffic light will remain green for nothing.

To enhance the efficacy of the solution, it is imperative to optimize the duration of the green light for each directional flow to maximize the throughput of exiting vehicles. Table 9 presents current situation and three distinct logical scenarios, which are subsequently compared with the optimal scenario. It's important to note that this optimization process was conducted utilizing Arena OptQuest. Arena OptQuest provides the identification of optimal solutions by systematically exploring the parameter space and evaluating various scenarios through meta-heuristic methods.

Utilizing Arena OptQuest and leveraging the arrival distributions and durations within the existing system, we maximized the number of vehicles exiting the intersection within a two-hour timeframe. The parameters utilized encompass the distributions and durations of vehicles arriving from four directions at the intersection, along with information regarding their intended turning directions. The optimal duration of green lights is sought within a wide interval ranging from 10 to 50 seconds. When defining the range for the sought-after duration of green lights, we aimed for a broad interval to ensure that the solution was not constrained by limits, while simultaneously verifying that it remained within feasible bounds. Furthermore, the total green light duration available at the intersection, i.e., the cycle time of the intersection, was predetermined as 85 seconds. This influenced our determination that the light in a single direction can have a minimum green light of 10 seconds and a maximum of 50 seconds. The other parameters entered into Arena OptQuest include the current green light durations written in the suggested values section. The search steps have been set to one for finding the optimal scenario. Through 5 replications, validated with a confidence level of 95%, the optimal solution is attained.

As seen in Table 9, when green light lengths are taken as 28, 11, 23 and 48 seconds for south, north, west and east directions respectively, the average number of vehicles leaving the system is more than the other scenarios. The optimal scenario increases the average number of vehicles leaving the system from 7997 to 8078. Moreover, in Table 10, it can also be seen that the total number of each type of vehicle in the Underpass Model is more than in the Current Model. This leads us to the fact that our alternative model increases the utilization of the junction and underpass.

Table 9.
Current System, Optimal Scenario, and Various Scenarios for Green Light Durations

Scenarios	S (in seconds)	N (in seconds)	W (in seconds)	E (in seconds)	Output (number of vehicles)
Current	11	15	32	27	7997
S1	20	20	15	15	7859
S2	20	20	10	10	8024
S3	25	25	20	20	8016
Optimal	28	11	23	48	8078

Table 10.
Number of each Type of Vehicles in Current and Underpass Models

	Current Model	Underpass Model
Car	7211	7273
Bus	307	316
Minibus	479	489
Total	7997	8078

On the other hand, it is expected to see some decrease in waiting times in each direction as well. As it can be seen in Table 11, in the current model, the number of vehicles waiting in the south and north directions are too many to congest the traffic of the junction. Hence, our proposed model decreases the number of vehicles in both queues by changing the green light length to 20 seconds for vehicles coming from north and south directions. This leads us to conclude the proposed model works well.

When considering queue length on a vehicle, lane, and direction basis, we can assert that the improvement between the proposed model and the current model is between 48% to 71%. This reduction underscores the need for further refinement and enhancement of our proposed model to better capture the intricacies of traffic dynamics and ensure its effectiveness in real-world applications.

In order to be more accurate, we ran our proposed simulation model with an Underpass example for 5 replications and 2 hours. According to Table 13, it can be concluded that the average waiting time in each direction does not change significantly when the number of replications changes for the Underpass Model.

To sum up, for our proposed model, we could increase the average number of vehicles leaving the system. Moreover, it was also possible to decrease the total number of vehicles waiting in the queue, especially, the total number of vehicles waiting in the south and north queue has dramatically decreased.

Table 11.
Average Waiting Times and Number of Vehicles in the Queues of the Current and Underpass Models

	Current Model		Underpass Model	
	Average waiting time / Max waiting time (seconds)	Average Number waiting / Max Number waiting	Average waiting time / Max waiting time (seconds)	Average Number waiting / Max Number waiting
Fatih from South	32.04 / 73.96	6.21 / 24	13.19 / 39.99	2.54 / 13
Fatih from North	29.02 / 69.93	7.66 / 32	12.86 / 39.96	3.578 / 19
From Şehitler (West) to South	16.79 / 52.96	5.15 / 29	21.49 / 49.92	0.73 / 5
From Sehitler (West) to North			20.79 / 49.99	1.93 / 12
From Kamil Tunca (East) To South	19.72 / 57.97	6.79 / 29	20.81 / 49.27	0.71 / 6
From Kamil Tunca (East) To North			19.51 / 49.97	1.22 / 8

Table 12.
Comparison of Average Queue Lengths for Each Vehicle Type Between the Current and Underpass Models

		Current Model		Underpass Model		Improvement	
		7:30 am - 8:30 am Length per lane (m)	8:30 am - 9:30 am Length per lane (m)	7:30 am - 8:30 am Length per lane (m)	8:30 am - 9:30 am Length per lane (m)	7:30 am - 8:30 am	8:30 am - 9:30 am
Fatih from South	Car	11.80	12.07	4.83	4.94	59%	59%
	Bus	2.27	1.89	0.93	0.77	59%	59%
	Minibus	1.66	1.33	0.68	0.54	59%	59%
	Total	15.73	15.28	6.45	6.26	59%	59%
Fatih from North	Car	14.54	14.70	6.79	6.87	53%	53%
	Bus	2.33	1.87	1.09	0.87	53%	53%
	Minibus	2.45	2.04	1.14	0.95	53%	53%
	Total	19.32	18.61	9.03	8.70	53%	53%
From Şehitler (West)	Car	10.01	9.90	5.16	5.11	48%	48%
	Bus	1.26	1.57	0.65	0.81	48%	48%
	Minibus	1.38	1.38	0.71	0.71	48%	48%
	Total	12.64	12.84	6.52	6.63	48%	48%
From Kamil Tunca (East)	Car	13.32	13.17	3.80	3.75	71%	71%
	Bus	0.83	0.83	0.23	0.23	71%	71%
	Minibus	2.17	2.17	0.62	0.62	71%	71%
	Total	16.31	16.17	4.65	4.61	71%	71%

Table 13.
Average Waiting Time for Each Direction in Each Replication for Underpass Model (in seconds)

Waiting Time	R1	R2	R3	R4	R5	Average
Fatih from South	13.19	13.35	13.14	13.37	13.89	13.39
Fatih from North	12.86	13.10	13.06	13.05	13.32	13.08
From Sehitler (West) to South	21.49	20.15	19.48	21.24	21.61	20.79
From Şehitler (West) to North	20.79	20.67	21.04	20.63	20.79	20.78
From Kamil Tunca (East) To South	20.81	21.64	20.63	21.78	21.49	21.27
From Kamil Tunca (East) To North	19.51	21.87	19.92	20.40	20.53	20.44

5.2. Propose a Roundabout

Our second proposed model was to apply a roundabout to the system instead of using traffic lights. In other words, we thought of changing this signalized system into an unsignalized system by eliminating traffic lights for all vehicles coming from each direction.

According to the articles we have searched for, a roundabout is a type of circular intersection or a junction in which road traffic flows almost continuously in one direction around a central island. Since the traffic flow is high from west to east and east to west direction, it is expected that a roundabout can also be used to improve the current system.

As seen in Figure 3, it can be realized that there is no traffic light ruling the traffic and the first vehicle coming to the junction is allowed to pass through the junction if it is empty.

Figure 3. A roundabout for traffic flowing on the left side

In our proposed model, since there are no traffic lights giving signals to drivers to stop or pass, we require a control mechanism to check whether the junction is empty or not. In order to apply this situation to the model, we eliminated all traffic lights and added two Assign modules in one of which the variable "JunctionFull" alters to 1 when the junction is occupied with a vehicle and in another one this value alters to 0 when the vehicle passes through the junction and junction is no longer occupied.

In this new proposed model, we again used Hold modules which seize the vehicles coming from each direction. But this time, these hold modules did not scan the condition of traffic lights, they scanned the condition of the junction according to "JunctionFull" value. When the junction is empty, Hold modules release a vehicle which is waiting in queue for the longest time and they continue keeping the vehicles when the junction is occupied with a vehicle.

After changing the hold modules and adding these mentioned assign modules, we ran the simulation model to see the results. Based on the newly found solution regarding the implementation of a roundabout, the comparison table is provided in Table 14. This update reflects the addition of the roundabout model and its respective vehicle counts compared to the current and underpass models. The roundabout model showcases significantly lower numbers of vehicles, indicating deterioration in traffic flow compared to the other models. Since the system is checking the condition of the junction for each vehicle in the system, it takes too long for a vehicle to pass through the junction and this situation increases the waiting time for each vehicle and the number of vehicles waiting in the queue. Unlike the traffic lights, checking the junction whether is occupied or not for each vehicle does not seem to be practical during rush hours. Therefore, it can be said that a roundabout can be used or applied to a system in which the traffic is not congested most of the time.

Table 14.
Number of each Type of Vehicles in Current, Underpass and Roundabout Models

	Current Model	Underpass Model	Roundabout Model
Car	7211	7273	1461
Bus	307	316	63
Minibus	479	489	98
Total	7997	8078	1622

To sum up, for second proposed model, a roundabout is not a good solution since the occupancy of the junction has to be checked for each vehicle and it also increases the risk of hazards when a risk-taking driver enters the system.

6. Conclusion

In this study, the traffic dynamics at the Vakıflar Junction in Izmir during rush hours were meticulously analyzed through simulations conducted using Arena software. The focus was initially on understanding the real-world scenario to determine the necessary simulation components. Essential traffic data were collected and analyzed to define the characteristics of the current traffic management system, which relied heavily on traffic lights. This system resulted in significant waiting times for vehicles, particularly in the north and south directions, and caused congestion due to the high traffic volume between the east and west directions. To address these issues, two main enhancements were proposed: the construction of an underpass for east-west traffic to bypass the junction and the adjustment of traffic light cycles to favour north-south movement. While the underpass aimed to alleviate congestion by providing an alternative route for the heaviest traffic flow, adjusting the traffic light cycles was intended to reduce waiting times for the most congested directions. Simulation results from five replications indicated an improvement, with an increased average number of vehicles exiting the system.

However, a proposal to replace the traffic light system with a roundabout, intending to streamline traffic flow further, did not yield the anticipated benefits. Increased traffic volume led to a higher number of entities in the simulation, ultimately worsening the system's performance. Considering the limitations observed, further investigations are warranted to explore the traffic flow during evening rush hours, as different traffic patterns might emerge, affecting congestion and queue dynamics. Incorporating detailed parameters such as vehicle sizes, and road widths, and distinguishing between different vehicle types can significantly refine the simulation model, allowing for more precise control measures and effective traffic management strategies. Moreover, analyzing the road network's capacity to handle varying traffic volumes could offer insights into alternative routing strategies, potentially reducing congestion and improving overall traffic flow across different times of the day. These enhancements would provide a comprehensive understanding of traffic behaviours and contribute to developing a more effective and efficient traffic control system at Vakıflar Junction.

Vakıflar junction in Izmir during rush hours was simulated in Arena to be analyzed and improved. First, the real situation was investigated to determine what modules and logic are needed to be considered in the model. Then, the necessary data for the developed model were collected and analyzed to specify the current system. In the current system, Vakıflar Junction was ruled by traffic lights and the waiting time for vehicles in queues, especially in the north and south directions was very long. Moreover, the traffic flow between the east and west directions was so high that the number of vehicles in the queue caused congestion in Vakıflar junction.

For improvement, it was recommended to construct an underpass between the east and west direction having the heaviest traffic at the junction. Since the volume was very high in these directions, the vehicles were able to use this underpass instead of waiting for green lights at the junction. Moreover, we changed the cycle time of traffic lights by increasing the length of green lights for south and north directions to reduce the waiting time and the number of vehicles waiting in the queues from the north and south directions. On the other hand, the green light lengths for vehicles directed to north or south directions from east or west are diminished since the high volume of the junction has shifted to north and south directions. To investigate the results, the simulation model was run for 5 replications and in each replication, the average number of vehicles leaving to system has increased.

We also proposed the construction of a roundabout for the system. In this proposed model, the traffic lights were removed and all vehicles were permitted to pass through the junction when the junction was empty. Due to the traffic volume increase in the junction, the number of entities increased and the system deteriorated. The model provided conclusive results for short time durations. Comparing the two proposed approaches over short time periods, it was observed that the construction of an underpass would be more beneficial.

Contribution of Researchers

Sinem ÖZKAN and Mert PALDRAK were responsible for data collection, modelling, analysis, interpretation, drafting and revising the manuscript, and contributing their insights to the discussion and conclusions. Erdinç ÖNER reviewed and refined the manuscript.

Conflict of Interest

There is no conflict of interest to declare.

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