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Research Article

Comparing Traffic Performances Between Signalized and Give-Way Roundabouts: A Case Study in Bursa

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Abstract

Globally developing economies and opportunities have caused an increase in the density of people in city centers in recent years; thus, an exponential increase has been experienced in the number of motor vehicles, which complicates the creation of a sustainable traffic network. Waiting times and the number of stops cause psychological, physical, and environmental problems. The efficiency of intersections is vital to ensure sustainable transportation. Modern roundabouts outperform signalized roundabouts, and their popularity has been increasing in recent years. However, the geometric features of intersections should be suitable for the location and traffic composition. In this study, the Durmazlar roundabout, which is currently a signalized roundabout in Bursa, has been transformed into a modern roundabout and redesigned. One of the aims of the study is to make minimal changes in the geometry of the roundabout. One-way road applications have been made to regulate entrances and exits on problematic roads. Modeling of the roundabout and collecting data was performed through the PTV Vissim software. Queue length, travel time, and speed parameters of the data obtained regarding the new scenario and the current situation were compared.

Keywords: Modern roundabout, PTV vissim, Signalized roundabout, Traffic simulation.

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1. Introduction

The constant growth of the world's population, as well as the number of motor vehicles providing transportation around the globe, creates several issues such as traffic accidents, congestion, emission, and noise pollution [1–4]. Due to the global Covid-19 pandemic, people's desire to provide more isolated transportation has caused travel modes to shift from public transportation to private motor vehicles. As a result of this situation, the number of motor vehicles has increased faster than expected, which emphasized the importance of traffic network enhancements [5–7].

The increased number of motor vehicles on urban roads has significantly increased traffic congestion [8–11]. As a result, waiting time in traffic, amount of fuel spent, and amount of emissions have increased. Also, the study showed that intersections account for 47 percent of death or injury incidents in urban areas [1]. To minimize these disadvantages, it is essential that intersections, which are the most important connectors of urban road networks, operate as efficiently as possible. Different types of intersection applications and different traffic control methods can be preferred to reduce traffic congestion [12]. Signalized roundabouts are one of the intersection types that has become less popular around the world in recent years. In addition, signalized roundabouts are one of the most vital elements of traffic conflicts in different modes of transport and in any transport network [3, 13–15]. Stoppages at traffic lights cause the majority of road delays. The number of traffic lights per kilometer, rather than the volume of traffic per lane or the volume-to-capacity ratio, is thought to have a greater impact on travel speeds [16]. This situation forces us to look for an at-grade intersection that can operate more efficiently than signalized roundabouts. In the light of the study, the use of modern roundabouts has increased in recent years despite the lack of definite criteria for the design and implementation of modern roundabouts which are seen to be more efficient than signalized roundabouts in many performance criteria.

In recent years, the microsimulation modeling method has been very popular in the transportation discipline. While a wide variety of simulation softwares and methods are available, PTV's Verkehr In Städten SIMulationsmodell (VISSIM) is widely preferred for its ease of use, speed of resolution, flexibility to create complex problems, and flexibility in simulating jurisdiction-specific networks [17–19].

In this study, the Durmazlar signalized roundabout (located in Bursa, Turkey) has been transformed into a modern roundabout, and all conditions have been investigated by redesigning it. The PTV Vissim software was used in the modeling of the roundabout. Afterwards, evaluations were made between the new scenario and the current situation.

2. Material – Method

The problematic intersections with high traffic density in Bursa province were investigated within the scope of the study. Bursa Metropolitan Municipality Transportation Coordination Branch Office was contacted and information was obtained related to the determined intersections in terms of traffic, accident, plan, expropriation, and the Durmazlar Roundabout that is located on the Boulevard Ata at Nilufer district was chosen for investigation. The features of the Durmazlar Roundabout, such as its being on the main artery, connecting the industrial zone of the province with the residential areas, having one entrance and one exit with non-ideal geometry, and being suitable for geometry changes in expropriation, have influenced the state of its being selected for the study. In Figure 1, the roads connected to the intersection are shown and numbered.

Figure 1. Roads connected to the Durmazlar Roundabout.

The road connected to the roundabout from the northeast direction is connected to the Sanayi Street that is the continuation of the Boulevard Mudanya and is numbered “1”. The road connected from the south is connected to the İzmir Street, which combines the roads in the directios to İzmir, Çalı, and Bursa, and is numbered “2”. The road connected from the northwest direction is connected to Bursa Organized Industrial Zone and Nilufer Organized Industrial Zone and is numbered “3”. The side road connecting the roads 2 and 3 is shown with the number “5”. The last road connected to the roundabout from the east is connected to the Ata Street and is numbered “4”. The PTV Vissim software was used to model the current geometric condition and to reflect criteria such as driver behaviors, traffic characteristics, vehicle tracking models, and signaling systems in the most effective way. The Vissim is a discrete-time micro-scale traffic simulation software that simulates and evaluates all road users in various situations, including intersection designs, urban road traffic, traffic lights, public transport systems, pedestrian movements, and their interactions.

2.1. Modeling of the Current Situation

The drawn model of the intersection area is given in Figure 2. Roads 1, 2, and 3 have been drawn as three lanes for departure and arrival, with a horizontal curve radius equal to the current situation on the satellite image. Lane widths are set at 3.5 meters, except where otherwise noted.

Figure 2. Model of the intersection area drawn in Vissim

In Figure 3, the irregularity is observed in the current state of the road 4. The road numbered 4 is modeled as two lanes, excluding the intersection entrance area. The simulation reflects the current confusion by setting the number of lanes as two arrivals and two departures at the intersection entrances and giving the intersection 3 lanes.

Figure 3. Irregularity on the road 4 in the current situation

Traffic data and signal times of the Durmazlar Roundabout were obtained through Bursa Metropolitan Municipality. Vehicle counts were performed in May 2018 and include peak values for the morning, noon, and evening hours. Vehicles arriving at and exiting the roundabout from all roads and routes are included in the data. The morning count with the highest number of vehicles was used in the simulation. In Table 1, the vehicle count data of the intersection are given.

Table 1: Morning peak hour of motor vehicle counts

	1	2	3	4	5	Total
Morning	1804	2929	1558	733	458	**7482**
1	11	1868	130	71	0	**2080**
2	1243	175	940	64	0	**2422**
3	550	204	0	598	458	**1810**
4	0	682	488	0	0	**1170**
5	0	0	0	0	0	**0**

The Durmazlar Roundabout signaling cycle time is 74 seconds. The signaling cycle diagram prepared in the Vissim is given in Figure 4.

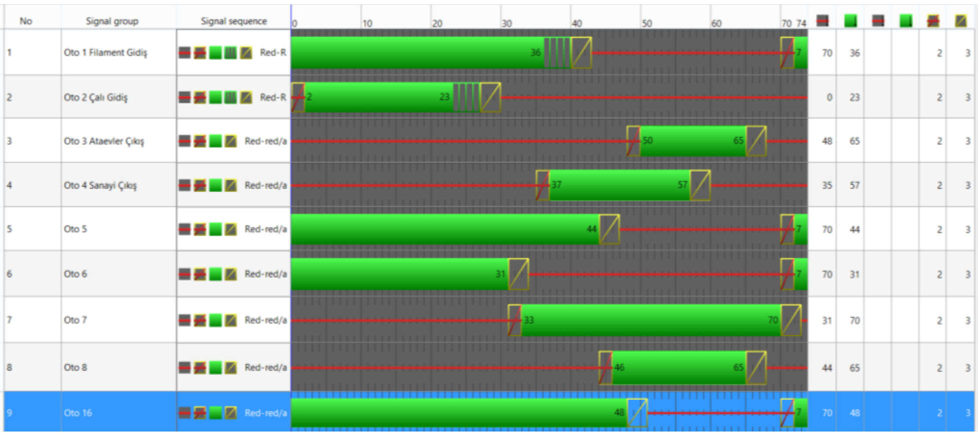

Figure 4. Current situation signaling cycle diagram

2.2. Modeling of the 4-Way Modern Roundabout

In this scenario, the Durmazlar Roundabout was designed as a modern roundabout by increasing the entrance slopes to the crossroads on each route and imposing speed limits at the intersection entrances. As for the information received from the municipality, a side road has been opened within the expropriation limit for the turns from the road numbered1 to road numbered 3. In addition, a U-turn road was built before the intersection for vehicles that come from the road numbered 1 and turn along the intersection and make a U-turn. Due to the geometrical aspects of the road 4, channeling for right turns from the road 2 to the road 4 was not possible. The road was built in order to make a U-turn before the intersection for vehicles that come from the road 2 and turn along the intersection and make a U-turn. For the turns from the road 3 to the road 1, no separate channeling was established and the existing side road 5 was used. A one-way application was made, with the entrances to the intersection from the road 4, which does not conform to the geometrically modern roundabout standards. A separator island was used to avoid confusion at the roundabout entrances and exits on the road 4. Reduced speed areas have been created by placing speed warning signs at the entrances to the intersection area. As a result of the arrangements made, the view of the intersection area is given in Figure 5.

Figure 5. 4-way modern roundabout modeling

Vehicles connected to the roundabout from the southern route of the road 4 were diverted to the road 2 before the intersection area with the existing crossing. Since the signaling system at the roundabout has been removed, the priority rule of the vehicle moving in the roundabout has been defined.

3. Results

This title refers to the result reached as a result of the modeling. The created scenario was compared with the current situation.

3.1. Current Situation

As in the on-site observations, a blockage occurred on the road 4 in the simulation as well. Although the roads 1, 2, and 3 were evacuated during the green light periods, they were subject to serious delays due to the congestion in the signaling located in the roundabout. Figure 6 shows the traffic congestions that occurred in the simulation.

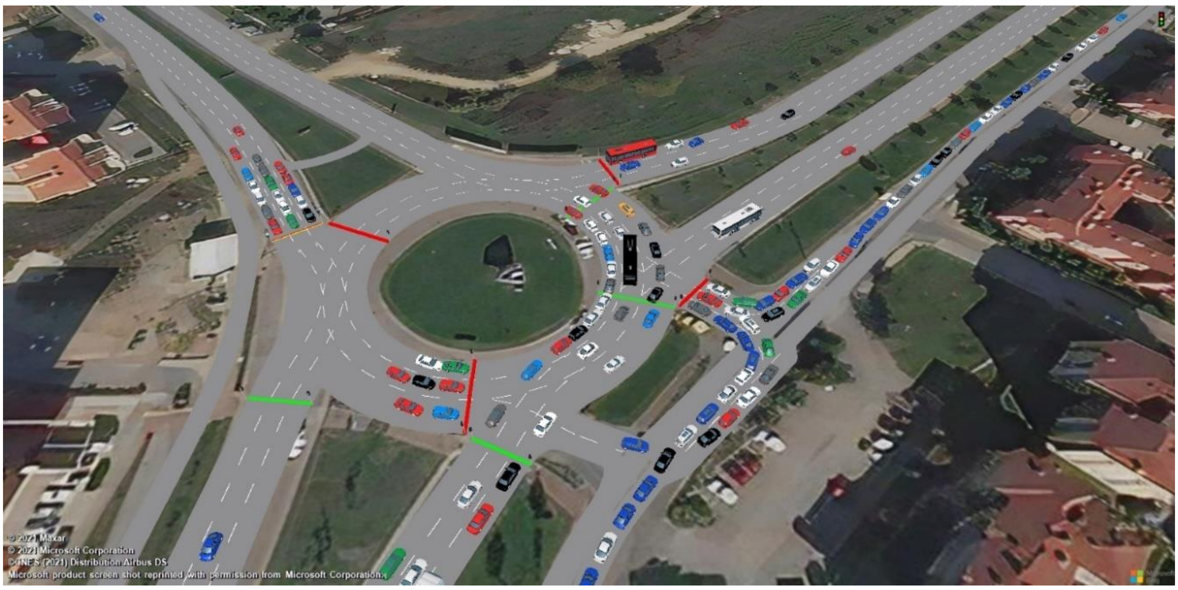

Figure 6. Congestion occurring in the current situation simulation

The average queue length, number of vehicles, and average speed data obtained for the current situation as a result of the simulations are given in Table 2.

Table 2. Current situation simulation “Queue Counter” and “Data Collection Point” data

Road	Avg. Queue Length (m)	Number of Vehicle	Avg. Speed (km/h)
1	23,97	2035	39,84
2	19,43	2419	26,05
3	22,55	1347	24,32
4	80,98	1166	20,9
5	0	441	50,14

The route and travel time of each vehicle entering the intersection are given in Table 3. Each routes travel time was measured from 50 meters before entering the intersection to 50 meters after departing the intersection. In addition to the number of vehicles and travel times, the total number of vehicles and average travel time for each road are given.

Table 3. Current situation simulation “Vehicle Travel Time” data

Route	Number of Vehicle	Travel Time (sec)	Number of Vehicle	Avg. Travel Time (sec)
1→1	10	81,99	2033	56,71
1→2	1830	30,15		
1→3	116	29,47		
1→4 down	35	65,27		
1→4 up	42	76,65		
2→1	1259	30,01	2404	47,29
2→2	166	85,72		
2→3	914	50,09		
2→4 down	29	21,15		
2→4 up	36	49,46		
3→1	565	72,63	1331	57,07
3→2	198	45,83		
3→4 down	266	47,15		
3→4 up	302	62,67		
4 down→3	268	56,58	1166	74,93
4 down→2	344	76,28		
4 up→3	240	75,44		
4 up→2	314	91,43		

The congestion in the road 4 that is shown by the simulation was supported by the values in the obtained data. As seen in the tables, the road 4 is the road with the highest average queue length and average travel time and the lowest average speed.

3.2. Modern Roundabout

Although traffic performances increased on the roads 2, 3, and 4 in the simulations, much more congestion occurred on the road 1 and long queues were formed. Average queue length, number of vehicles and average speed data of the four-way modern roundabout simulation are given in Table 4.

Table 4. Four-way modern roundabout simulation "Queue Counter" and "Data Collection Point" data

Road	Avg. Queue Length (m)	Number of Vehicle	Avg. Speed (km/h)
1	258,35	1829	13,57
2	65,58	2342	17,47
3	39,54	1334	12,62
4	11,11	693	10,71
5	0	442	60,42
1→3	0	115	61,28
1U	0	9	32,83
2U	0,87	528	31,43

For the four-way modern roundabout, the route and travel time of each vehicle entering the intersection are given in Table 5. Travel time of each route was measured from 50 meters before entering the intersection to 50 meters after departing the intersection. In addition to the number of vehicles and travel times, the total number of vehicles and average travel time for each road are given.

Table 5. Four-way modern roundabout simulation "Vehicle Travel Time" data

Route	Number of Vehicle	Travel Time (sec)	Number of Vehicle	Avg. Travel Time (sec)
1→1	8	13,68		
1→2	1572	60,98		
1→3	104	8,53	1752	37,61
1→4 down	30	43,79		
1→4 up	38	61,08		
2→1	1258	27,12		
2→2	533	11,82		
2→3	1045	30,01	2901	23,16
2→4 down	29	19,04		
2→4 up	36	27,83		
3→1	570	34,52	1340	32,99
3→2	199	31,7		

3→4 down	268	26,24		
3→4 up	303	39,48		
4 up→3	363	30,5	688	31,65
4 up→2	325	32,79		

Among the examined routes, only the travel time of the route from the road 1 to the road 2 increased, while the remaining fifteen travel times decreased. The travel times comparisons of the current situation and four-way modern roundabout simulations are given in Figure 7.

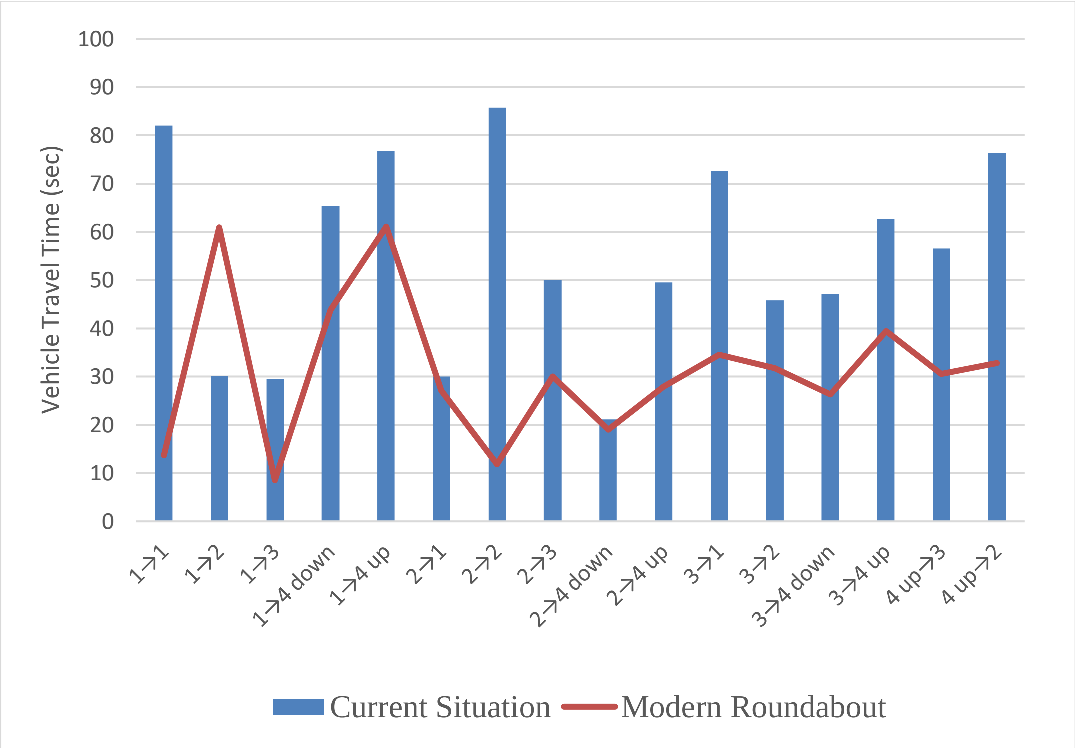

Figure 7. Comparison of the current situation and modern roundabout vehicle travel times

The comparison of the four-way modern roundabout simulation data with the current state data is given in Table 6.

Table 6. Comparison of the current situation and modern roundabout simulation results

	Avg. Queue Length (m)	Number of Vehicle	Avg. Speed (km/h)	Avg. Vehicle Travel Time (sec)
Current Situation	29,39	7408	32,25	58,22
Modern Roundabout	74,92	7292	30,04	31,19
Change (%)	154,94	-1,57	-6,85	-46,42

As can be seen in Table 6, although the performance of the road 4 improved as a result of the changes made, the average queue length, which is one of the performance parameters, increased at a high rate of 154,94% in total.

However, the average vehicle travel time has decreased by 46,42%. Since the amount of vehicles given to the system is the same, it is not expected to change much in the number of vehicles. Thus, the number of vehicles using the intersection area showed a decrease of as low as 1,57%. The average speed of the system also decreased by 6,85%.

3.3. Statistical Analysis

In order to examine the comparability of the mean values of the obtained data, the data were analyzed with the t-test method. Queue length and speed parameters were interpreted by comparing their mean values and variances since they did not have enough data to perform the t-test. For the vehicle travel time parameter, the t-test was applied assuming that the data were normally distributed. Hypotheses are established for the t-test:

H0= Means are equal

Ha= Means are not equal

Data analyzes made in R studio program are given in Figure 8.

```
> attach(mevcut)
> attach(senaryo2)
> mean(QLEN)
[1] 29.386
> mean(KYRK)
[1] 74.916
> var(QLEN)
[1] 925.1659
> var(KYRK)
[1] 11167.57
```

```
> attach(mevcut)
> attach(senaryo_2)
> mean(SPDAVG)
[1] 32.25
> mean(ORTSRT)
[1] 30.04125
> var(SPDAVG)
[1] 151.9519
> var(ORTSRT)
[1] 430.7099
```

```
> attach(mevcut)
> attach(senaryo2)
> mean(TRAVTM)
[1] 58.22056
> mean(dortkolsure)
[1] 31.19438
> var(TRAVTM)
[1] 462.9256
> var(dortkolsure)
[1] 227.958
> t.test(TRAVTM,dortkolsure)

        Welch Two Sample t-test

data:  TRAVTM and dortkolsure
t = 4.2751, df = 30.459, p-value = 0.000174
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 14.12344 39.92892
sample estimates:
mean of x mean of y
 58.22056  31.19438
```

Figure 8. Statistical data analysis steps

As a result of the t-test, the p-value was found to be 0,000174. Since the p-value obtained was less than the minimum value of 0,05, H_0 among the hypotheses established at the beginning of the test was rejected and H_a was accepted. Thus, it has been determined that there is a statistically significant difference between the averages of the travel time data groups of the current situation and modern roundabout scenarios. In the queue length and speed data, which do not have enough data to apply the t-test, the increases or decreases in the averages were supported by the variance values.

4. Conclusion

In the modeling, the signaling systems at the existing roundabout were removed. Arrangements were made in the roundabout area according to the modern roundabout design standards. It has been redesigned by making one-way application on the road 4, which does not comply with geometric standards. With the arrangements made, it was desired to investigate how a modern roundabout, which does not have ideal design features, will perform. As a result of the simulations, the excessive congestion that occurred on road 4 in the current situation was eliminated, but this time excessive congestion occurred on the road 1. The average queue length across the roundabout increased from 29,39 meters to 74,92 meters. While the variance was 925,17 in the current situation, as a result of changing the roundabout type, it increased approximately 12 times and became 11167,57. These values showed that the average queue length data were measured at extreme values, while excessive congestion occurred on the road 1 in the simulation while supporting the operation of the other roads without congestion. Average speed decreased from 32,25 km/h to 30,04 km/h. While the variance of the speed parameter was 151.95 in the current situation, it was calculated as 430,71 as a result of the modification. In the current situation, the density of vehicles accumulating around the rotating island has shifted to the entrance area of the roundabout after the arrangements made. Although there was an improvement on the problematic road numbered 4, this improvement negatively affected the road numbered 1. Despite all the negativities, thanks to the removal of the signaling in the roundabout, the average travel time of vehicles has decreased from 58,22 seconds to 31,19 seconds since they entered the roundabout area. The decrease in the variance from 462,93 to 227,96 supported the improvement in the travel time parameter. As a result of the t-test applied, the p-value was 0,000174. Thus, the null hypothesis was rejected and it was determined that the change was significant. The roundabout type change had a negative effect on the queue length and speed data, but it was reflected positively on the travel time parameter. The results showed that the transformation of the selected roundabout into a modern roundabout with non-ideal geometrical conditions will not yield positive results in the current traffic conditions and geometric conditions.

As seen in the simulations, the fact that even one road does not comply with the design standards in the modern four-way roundabout model has seriously affected the performance of other roads and reduced the performance of the intersection. This has demonstrated the importance of design standards in modern roundabouts.

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