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Research Article

INTERSECTION SIGNALING SIMULATION

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ABSTRACT

The number of vehicles registered to traffic increases rapidly every year in Turkey. According to Statistics of The Number of Road Motor Vehicles published by Turkish Statistical Institute, the number of vehicles registered increased by 72% during the period of last 10 years in Turkey. In the same period, the increase in the number of vehicles registered was 103% in Trabzon, the city in Turkey. This increase causes serious traffic congestion in the city center of Trabzon located in a restricted geographical area, and has a road problem. It is quite costly to assess solutions in the city where construction activities are making life difficult while applying various methods to solve the traffic intensity. Simulation models should be considered in such situations due to their non-cost. In this study, the traffic of the Maçka intersection located at one of the most central and active points of the city was analyzed. The data collected from intersection was modeled by Arena Simulation software according to traffic flow. Various scenarios were produced according to traffic light periods, and trials were carried out to improve current traffic flow by evaluating the outputs obtained by modeling of these scenarios. Two different time periods that have heavy traffic, morning and evening, were examined. The scenario in which the best outputs were obtained was presented as a solution. According to results of this scenario, a 13% improvement in average waiting time can be achieved.
Keywords: Intersection, traffic, simulation, signaling.

1. INTRODUCTION

Transportation has a great impact on the economic, social and cultural aspects of city life. The inability to correctly design roads and insufficient infrastructure (lack of proper road infrastructure) of roads cause increase in the transportation costs considerably both in terms of economy and time. One of the most important issues (problems) arise in roads due to inadequate transportation infrastructure is traffic congestion. Traffic congestion causes many problems, such as air pollution, noise pollution, economic problems, and too many time in road. The one of the main reasons of th e traffic congestion is that signalization systems that traffic flow is controlled are not optimized and updated.

Authorities have using more computerized traffic signal systems since early 1960's to prevent traffic congestion. Signalization systems are widely used in control of intersection traffic as well as in many road elements. These systems have an important place in use of the intersection

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capacity actively / efficiently / effectively while providing the safety of the vehicle and the pedestrian. Non-optimized signalization systems lead to deterioration of the traffic flow gradually, long vehicle queues on the roads meet with intersections and increase in waiting times at traffic lights. As a consequence of these, a traffic where rules and regulations are disregarded occurs. To eliminate such negative effects occur in traffic, one of the solutions needed is to optimize the signalization systems. Traffic signaling applications generally use fixed time signaling, whose light cycle length and order are predetermined. In addition, in some applications, dynamic signalization systems that have variable signal cycle length are used. In such practices light periods and orders are arranged according to traffic flow intensity by expert systems at various times of a day.

Simulation is a cheap and powerful technique for understanding the current situation in a short time. It can be helpful for supporting decision making process [1]. Therefore, researchers who are working for solving traffic congestion have done many studies with using simulation models for traffic flow since early 1990's.

Schaefer et al.'s research has been performed to analyze the percentage of drivers that must comply with lane control. A simulation model was developed and tested in their work. The simulation results showed that lane control has little influence on traffic congestion [2]. Stollova and Stollov, in their study, built a simulation model on light's duration to reduce noise level with environmental pollution [3]. Chen and Yang developed an algorithm to find a shortest path to simulate the traffic light control operation in a city [4]. Wen and Yang developed a dynamic model and automatic light control system to reduce traffic congestion [5]. Kamarajugadda and Byungkyu developed a stochastic traffic light's duration optimization model to consider stochastic variability. The purpose of this research was to estimate variability in delay at signalized intersections and incorporate the variability in the optimization process [6]. Hewage, and Ruwanpara showed how to provide routing behavior. Based on routing information, the high level specifications are translated into cellular models that execute those specifications to describe path selections and vehicle routing in the city with the help of ATLAS which is a specification language defined to outline city sections for modelling and simulation of traffic flow [7].

Ocakdan, in his study, modeled the traffic flow of multi-intersections on Nuhkuyusu Avenue in İstanbul through SimTraffic program. The author proposed two scenarios and investigated which one would be beneficial to use. In result of his study, he showed that traffic congestion could be reduce even if only signal times changed [8]. Hewage and Ruwanpura designed a simulation software and sought solutions to reduce the traffic congestion in Japan with an optimized traffic light signal timing. The authors showed that the software was a good platform to analyze traffic data and costs effectively and efficiently [9]. Li and Shimamoto, also, built simulation models for dynamic and fixed-time signalization in their work. In addition, the authors proved that CO_2 emission could be reduce in traffic controlled by dynamic signal timing [10]. Wen has analyzed the effects of the traffic patterns obtained by the RFID readers and the time periods determined by the simulation models and the time-varying traffic signaling times [11]. Wen examined the effects of dynamic signal timing on traffic using various simulation models based on data obtained from Radio-frequency identification (RFID) readers [11]. Ezzat et al. dealt with a traffic network consists of two intersections connected each other for the city of Alexandria in Egypt. In their study, current traffic flow that had excessively long vehicle queues and long waiting times were represented "Scenario 1". The authors claimed that mean number of vehicles waiting and mean waiting time could be reduced by 36% and 32%, respectively according to alternative scenario proposed. [12]. Fouladvand et al. studied the traffic flow of an intersection by simulating the flow according to fixed-time and time-varying light periods. In their study, the authors were stated that the model generated using time-varying light periods that change with the vehicle queue length limits, gave the optimum result [13]. Stevanovic et al. surveyed a road network consisting of 12 intersections in Florida. They carried out multipurpose optimization that targets both traffic safety and the best value of traffic efficiency. The scenarios created by determining the light durations with genetic algorithm were evaluated by simulation to obtain optimum light durations. With the best model proposed in the study, the traffic conflicts were reduced by 9% with only about 1% loss of efficiency [14].

Unlike previous studies in the literature, this study focused on road intersection shared by six roads using two traffic lights and this road intersection is the bussiest point in a city which a pollution of a approximately 800000.

2. MATERIAL AND METHOD

Within the scope of the study, a simulation model of road intersection that located in vicinity of Trabzon city center has been prepared. The intersection is one of the busiest points of the city and is shared by six roads. Map of the intersection, which is called Maçka Intersection, is shown in Fig. 1.

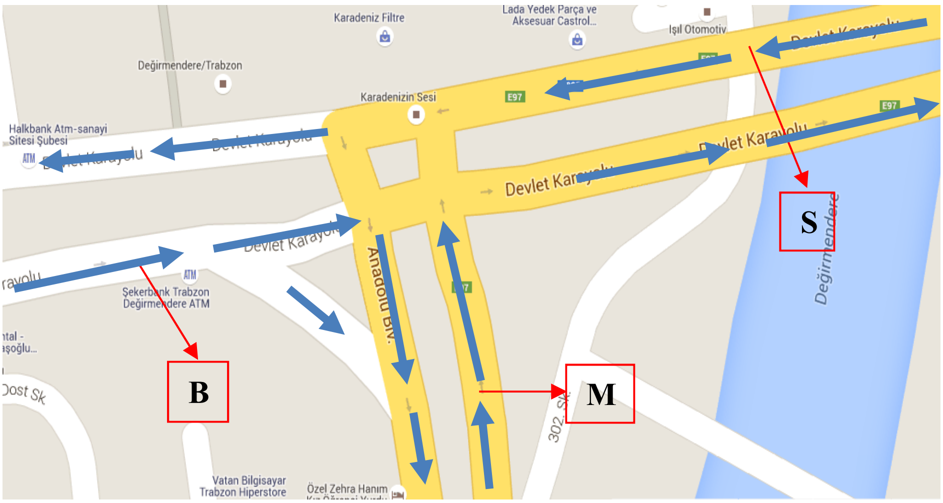

Figure 1. Map of Maçka Intersection

Images of Mobile Electronic System Integration (MOBESE) cameras were monitored to determine the density of the traffic at different times of the day accurately. The number of vehicles according to direction of traffic flow were determined. Since the MOBESE images were taken from Trabzon Directorate of Police, a limited number of images were analyzed and the model was built. The data used in the model were obtained from images of rush hours, 07:30 - 08:30 and 17:30 - 18:30 of 29 February 2016 and 3 March 2016.

The traffic of the intersection has three flow direction. The direction from Maçka is denoted by M, from Shopping Mall is denoted by S and from bus terminal is denoted by B. All directions are dual carriageway. The directions and the denotations are illustrated in Fig. 1.

Vehicles coming from the M, S and B roads to the intersection may go to different directions after waiting in the traffic lights. The vehicles coming from the B road can continue to the M or S road. M road from the intersection has no traffic light and MOBESE does not record traffic of this road. The vehicles that are routing here continue without waiting due to lacking of traffic light. So the number of vehicles routing from the B road to the M road is negligible for simulation model and the effect of the vehicles routing from the B road to the M road was ignored for the general traffic intensity of the intersection. Vehicles coming from S road can continue B or M roads. Vehicles coming from the M road can continue S or B roads. All roads except the B road are composed of 3 traffic line width, but B road is composed of 2 traffic line width. Total vehicle numbers according the vehicle types for the Maçka intersection at the specified hours and days are as shown in Table 1.

Table 1. Total vehicle numbers according to vehicle types for the Maçka intersection

Maçka Intersection	Date	Time	Automobile	Minibus	Bus	Truck	Total
From S to B	29.02.2016	07:30 - 08:30	938	415	59	131	1543
From B to S			590	257	68	53	968
From M to B			394	190	10	118	712
From M to S			163	30	3	66	263
From S to B	03.03.2016		883	393	64	117	1457
From B to S			583	275	68	51	977
From M to B			348	162	13	101	624
From M to S			169	38	5	78	290
From S to B	29.02.2016	17:30 - 18:30	925	270	50	121	1366
From B to S			638	192	38	55	932
From M to B			526	175	9	80	790
From M to S			261	44	3	59	367
From S to B	03.03.2016		929	243	45	118	1335
From B to S			656	160	36	53	905
From M to B			614	133	20	80	847
From M to S			344	36	5	68	453

The collected data were analyzed in the Arena Input Analyzer Module for four different types of vehicles: automobiles, minibuses, buses and trucks, which have different passing times from light. The arrival time interval distribution were determined for each vehicle type. The simulation model's inputs were set up for each different vehicle type according to their distributions. For vehicles coming from three different directions, three different Create Modules were used. Vehicles (entities) were separated by type with the Decide Module after being inserted into the system with Create Module. Also an Assign Module was used to label the vehicles as types. Thanks to Create Module, Decide Module and the Assign Module, the system produces vehicles according to the distributions and shows what types vehicles they are to simulation model. The Attribute feature which is part of Assign Module was used to assign the passing times of the vehicles from the lights.

Integrating traffic lights into the simulation model is one of the most important parts in this study, after vehicle types and interval times to be used in the simulation model have been defined. In this study, the traffic lights were formed with a Process Module. It is obvious that, the passing times of each vehicle from traffic light is different. That is, when the traffic light turns green automobiles, minibuses, buses and trucks have different passing times. According to the analyzed MOBESE images, the average passing times of an automobile, a minibus, a bus and a truck are 1 second, 1.5 seconds, 2.5 seconds and 3.1 seconds, respectively. The passing times of every vehicle types were used in Process Modules. Thanks to Failure Module, red light times were integrated to each traffic light as a failure.

In the simulation model, two different lights are placed for the B road. One of these lights serves for vehicles that come from B road and continue to M road. The other light serves for vehicles that come from the B road and continue straight on the road. In the model, arriving vehicles decide on direction with the Decide Module and go to the lights of this direction. Percentages of vehicles coming from B road - continue to M road and straight on the road were determined, and these percentages were integrated to model with Decide Module.

The procedures akin to B road procedure was performed for M and S roads. But, there is two options for M road instead of continue straight. One option is to turn to B raod and the other is to turn to S road. The simulation model used in this study is shown in Fig 2.

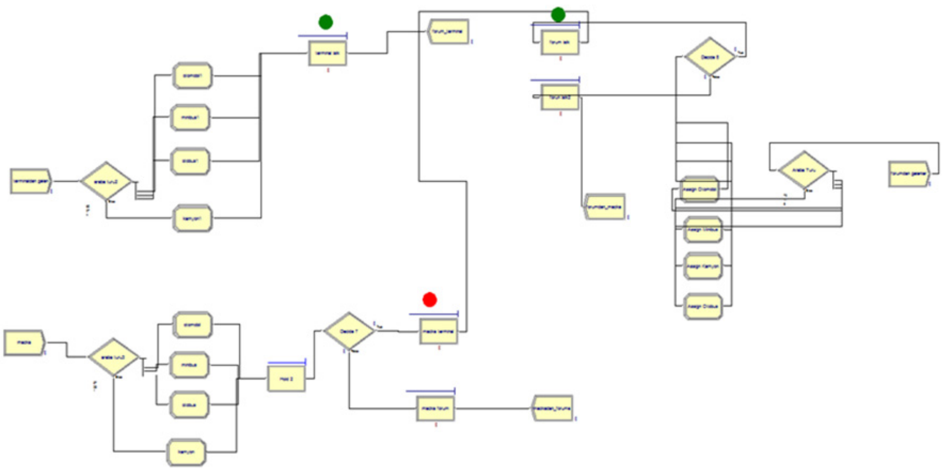

Figure 2. The simulation model created with ARENA

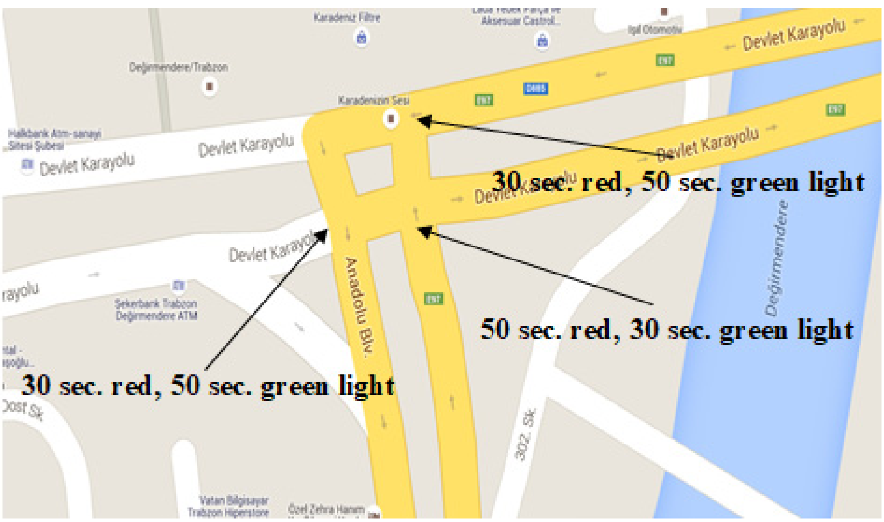

Figure 3. The current traffic light periods at Maçka Intersection

The red and green light durations for vehicles coming from the M road and the durations for B and S roads are opposite. Namely, when M's traffic light turns red, B and S's traffic lights turn green. The durations of red and green lights for M road are 50 seconds and 30 seconds, respectively. The durations are summarized in Fig 3.

The Process Module which represents the light of the M road are interconnected with Hold Module to ensure that the durations of the lights work in reverse order.

Dispose Module was used to allow the vehicle to exit from the system, after the creation of the modules of all roads at the intersection. The intersection has three different exit legs. So, three different Dispose Modules were used for outputs of the model.

2.1. Model Verification and Validation

In order to ensure that the model is correct and simulation logic is correctly implemented, we have conducted model verification and validation. First, given that waiting times at light of vehicles coming from S road are not affected by the number of vehicles coming from B road. Waiting times have been obtained for different scenarios which include different number of vehicles coming from B road. As expected, the all scenario results showed that waiting time of vehicles coming from S road were zero. Second, knowing that, the number of automobiles coming from S road and continue to B road should be around 920, for pilot assignment, simulation model have been run for such scenario 10 times and reported number of automobiles in Table 2.

Table 2. The number of automobiles for replications.

Replication	1	2	3	4	5	6	7	8	9	10
# of Automobiles	923	924	940	918	912	925	920	927	909	915

As can be seen at significance level of 1% the T-test p-value calculated and found as 0.88, which implies that the null hypothesis which is there is no relation between number of automobiles coming from S road is around 920 is not rejected, and this test validates the simulation model, as well. Lastly, operational behavior of simulation model have been checked. As the number of arriving vehicles increases, the waiting times at light also increase as it should be.

3. RESULT AND DISCUSSION

The model represents the current system was run and the following results were obtained.

- The average number of vehicles waiting at the light of S road is 3.06, while the average waiting time is 6.45 seconds.
- The average number of vehicles waiting to turn to S side at the light of M road is 1.55 while the average waiting time is 15.4 seconds.
- The average number of vehicles waiting to turn to B side at the light of M road is 3.23 while the average waiting time is 16.88 seconds.
- The average number of vehicles waiting at the light of B road is 1.86, while the average waiting time is 6.29 seconds.

Several scenarios which use different traffic light durations were made to reduce waiting times at traffic lights. The simulation model was revised according to each scenario. Revised simulation models ran separately. The results of these models are summarized in the Table 3. The scenarios were compared by calculating the score given in Table 3. The score was calculated using Formula (1).

$$Score = average\ number\ of\ waiting\ vehicles * average\ waiting\ time \quad (1)$$

Table 3. The results of various scenarios for signal timing

Light Duration (Sec)		**Average Waiting Time (Sec)**				**Average Number of Waiting**				**Score**
Green	Red	t (S)	t (M to S)	t (M to B)	t(B)	n (S)	n (M to S)	n (M to B)	n (B)	
30	30	8,87	7,85	7,78	8,25	4,20	0,79	1,49	2,44	75,18
35	30	8,20	9,78	10,20	7,96	3,87	0,99	1,40	2,35	74,40
40	30	7,66	11,72	12,57	7,27	3,61	1,18	2,39	2,15	87,16
45	30	7,10	14,07	14,53	6,51	3,37	1,42	2,78	1,92	96,80
50	30	6,45	15,40	16,88	6,29	3,06	1,55	3,23	1,86	109,83
35	35	10,59	8,95	9,53	9,74	5,00	0,91	1,83	2,88	106,59
30	35	11,03	7,19	7,52	10,71	5,21	0,73	1,44	3,17	107,49
40	35	9,64	11,08	11,44	8,98	4,57	1,12	2,19	2,65	105,32
45	35	8,85	12,40	13,64	8,68	4,19	1,24	2,61	2,57	110,37
50	35	8,74	15,28	15,97	8,03	4,12	1,54	3,05	2,37	127,28
36	30	8,11	10,31	10,28	7,32	3,83	1,04	1,88	2,16	76,92

After reviewing the present situation, the simulation model was set up to reduce the wait times by changing the light durations and setting scenarios for different light durations. The results of this scenario are summarized in the following table. Comparison of scenarios is provided by calculating the score in Table 3. Scenario score; the average number of vehicles waiting in each light was found by adding the values obtained by multiplying by the average waiting time.

4. CONCLUSION AND RECOMMENDATIONS

In this study, a variety of trials on traffic light signal timing for intersection of Maçka in Trabzon were carried out without any financials costs. The best signal timings were determined for rush hours by comparing the results of these trails. According to this, the duration of green light, that is now 50 seconds, should be 35 seconds and the duration of red light should stay as 30 seconds. Therefore, average waiting time at light(s) could be decreased from 9.3 seconds to 8.17 seconds. 13 percent improvement could be ensured for average waiting time. In addition, 40 percent improvement could be ensured for average waiting time for M that has longest waiting time at lights as 16.88 seconds. When performing a comprehensive intersection simulation analysis, data such as the size of the vehicle, the speed magnitudes of each vehicle type, and the capacities of the roads are needed in addition to passing times of the vehicles. A more powerful simulation model can be established using this data. The necessary data for simulation models could be obtained from these traffic control centers and Electronic Detection Systems (EDS). This data plays key role for building mathematical and simulation models that help solving traffic problems. Long-term useful light periods can be obtained by establishing simulation models with multiple intersections. The traffic congestion at any intersection is related to intersections which have connection to that intersection. So more complicated simulation models can help the authorities to reduce traffic congestion.

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