



**Research Article**

**THE EFFECTS OF OPERATION MODE OF SIGNAL CONTROL ON SIGNALIZED INTERSECTIONS: CASE STUDY FOR İSTANBUL HACIOSMAN ARTERIAL**

**Sencer OKTAV<sup>\*1</sup>, Halit OZEN<sup>2</sup>**

<sup>1</sup>*İstanbul Bilişim ve Akıllı Kent Teknolojileri A.Ş. (İSBAK), İSTANBUL*; ORCID: 0000-0002-7721-9524

<sup>2</sup>*Dept. of Civil Eng., Yıldız Technical University, İSTANBUL*; ORCID: 0000-0003-4031-7283

**Received: 06.06.2020 Accepted: 02.12.2020**

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**ABSTRACT**

The number of metropolitan cities all over the world is increasing day by day. Similarly, traffic growth caused by growing population has also become a major problem nowadays. Especially in urban areas, one of the important issues is controlling the traffic at intersections by traffic signalization systems in general. An effective and feasible traffic control system is essential to cope with fluctuating traffic demands increasing day by day. In this context, it is necessary to understand the correct choice and preferred reasons for choosing the operation modes of traffic signal control systems. There are four common types of traffic signalization operating modes, which are pre-timed, semi-actuated, fully actuated and adaptive mode. These modes are also operated as isolated or coordinated with the nearby intersection according to their requirements. In this study, first the types of operations for traffic signalization systems are explained, and it is stated that which type should provide the solution in which conditions and why it should be preferred. Then six different scenarios were developed by using the mentioned signal operation modes for the three signalized intersections in the Istanbul Haciosman arterial. It is aimed to minimize the delays for mentioned arterial and intersections. For each scenario, necessary optimization and simulation studies were carried out with Synchro Studio, which is one of the micro-scale traffic simulation programs, and the results were compared. Finally, in one of the intersections, traffic volumes were increased and a study was conducted in order to discuss the feasibility for the usage of traffic sensors under oversaturated traffic conditions.

**Keywords:** Traffic signalization systems, signalization operation modes, pre-timed signals, semi-actuated signals, fully actuated signals, adaptive signals, smart junctions, signal optimization, simulation.

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**1. INTRODUCTION**

Due to the explosion of population growth in urban areas, the number of large and mega cities are increasing mostly in the developing or emerging countries. The large cities complaint not only about traffic problems, but the traffic problems come to the forefront. Lack of road infrastructure, inadequate public transport facilities and uncoordinated transport and urban planning can be found frequently in large cities of emerging countries. Transport problems are getting even worse by lacking traffic education and undisciplined driving behaviour [3]. In the twenty-first century, the increase in traffic caused by the increasing population has become a big problem today. This

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<sup>\*</sup> Corresponding Author: e-mail: senceroktav@gmail.com, tel: (532) 270 36 60

traffic issue has been minimized through the development and implementation of technical and science in developed western countries [5].

Traffic Control of intersections plays an important role in the urban traffic control. It is substantially performed by using signalizations systems. In the control process of an intersection it is aimed that the performance losses due to delays and stops are minimized and the benefits for all road users are maximized. The basic control mechanism used for this purpose at signalized intersections is the signal timing [6].

Traffic signalization systems are used to provide both the safety of pedestrians and vehicles and the capacity increase of the roads. However, improperly applied or inadequate signalization designs cause accidents, reduce capacity and increase the delay times of vehicles by increasing vehicle queues at intersections and lead to incitement to violations of the rules. In order to prevent or reduce such negative effects, the signalized intersection must be designed properly and the signalization operating mode must be chosen correctly [4].

Traffic signals are indispensable control method of urban areas. Most probably, this will not change even if the cities grow further. However, it is inevitable that the problems experienced with an inaccurate traffic signal operation will grow even more especially with the increasing and fluctuating traffic demand. Therefore, there is a need for an effective and applicable traffic control system to cope with the increasing and fluctuating traffic demand [3].

When the urban road transportation is evaluated by vehicle-km unit, 2/3 of them are realized in the road network controlled by traffic lights. When the urban road transportation is evaluated with the vehicle-hour unit, more than 2/3 of the road transportation takes place in the road network controlled by traffic lights. The performance of urban road transport is therefore largely dependent on the success of road traffic control. The success of road traffic control depends on the realization of a correct signal operation at the signalized intersections [6].

## 2. TRAFFIC SIGNALIZATION CONTROL SYSTEMS

Signals are traffic control devices used to provide a regular and safe flow on roads and especially at junctions. Signalization is a lighted sign placed on the surfaces indicated on the junctions. These signs are used for the safety and control of traffic. It is necessary for drivers and pedestrians to have the meaning of the signs clearly. And the signs must attract the attention of drivers and pedestrians, and most importantly they must give drivers enough time to stop or pass [5].

Signalization facilities are usually installed to increase security, to regulate vehicle movements and to increase intersection capacity. However, a signalization system that is randomly established and not complied with the criteria of necessity causes both delays and increased number of accidents [3].

The capacity of a signalled intersection is generally higher than the capacity of an intersection of the same geometry, which is only controlled by traffic signs. Nevertheless, the signalization facility has a negative effect on delays unless the total traffic loads for the intersection reach a certain level. If the vehicle density is low, signalization causes higher delays; though, it is known that delays may increase rapidly if there is no signalization as vehicle density increases at the same intersection. It is also known that the total delay is still increasing at a signalized intersection as vehicle density increases but the rate of increase is slower [5].

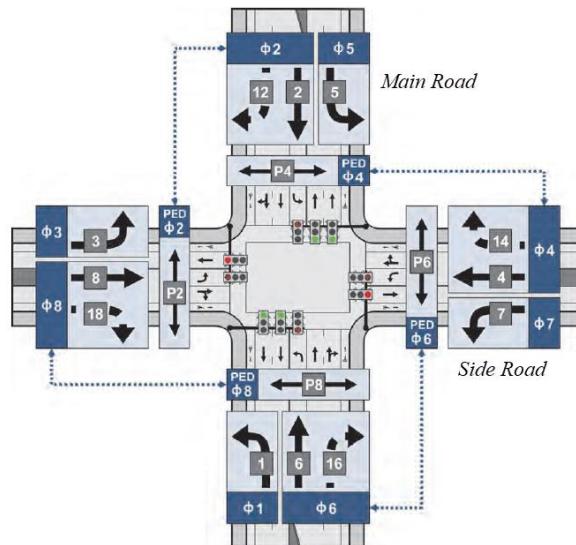
As a result of research conducted in various countries, it has been observed that traffic accidents in the form of collision of vehicles to pedestrians and collision of vehicles to vehicles have decreased significantly at three and four-arm junctions after being signalized [4]. To summarize, accidents should be expected to be greatly reduced at the point where the signalization facility is installed; nonetheless, the behaviour of drivers has a significant impact on this too [5].

In order to establish a signalization facility at any intersection or crosswalk, there must be a sufficient number of reasons such as intersecting traffic loads or number of accidents [4]. However, a very high rate of traffic intersecting at an intersection or frequent traffic accidents does not indicate that the only way to ensure the traffic order is signalization [3]. In other words, signalization is not required due to traffic characteristics at some point; primary, the establishment of a signalling facility is considered, and then it is investigated whether there are sufficient conditions or not. For this reason, the minimum requirements for the facility to be installed at any point must have been realized [5].

### 3. OPERATION OF TRAFFIC SIGNALIZATION SYSTEMS

The choice of signal management in a traffic network directly affects the route selection behaviour of the drivers as it directly affects the total travel time on the roads. The decisions made by the users come together to influence the overall flow pattern of the road network [8]. Therefore, after the decision to establish a signalization facility, the selection of the operating mode of the system must be followed in accordance with certain criteria [4]. For example, if several intersections are going to be signalized, they should be evaluated to be isolated or coordinated. Also the intersecting traffic loads should be considered for the selection of operating mode like actuated or pre-timed systems. For the selection of coordinated intersections, the vehicle densities and flow velocities must be evaluated together with the purpose of the coordination [5].

A typical four-arm intersection is shown as an example in Figure 1 to illustrate the elements that is needed to be evaluated for programming a signalized intersection. For each approach, elements such as number of vehicle and pedestrian groups, phase numbers, nature of the road and direction of flows are schematically indicated [2].



**Figure 1.** Schematic representation of four-armed signalized intersection elements [2].

There are some criteria that determine the operational performance of signalized intersections. These standards are capacity, volume-capacity ratio, delays, level of service, queue length, etc.

When deciding the operating mode of a signalized intersection, these standards must be taken into account and the most appropriate mode must be determined after the necessary calculations [1].

The level of service criteria for vehicles known as one of the most important criteria for the evaluation of the performance of signalized intersections is classified as shown in Table 1 related to the volume-capacity ratio. The best level of service is considered to be Class A and the worst level of service is considered as Class F [1].

**Table 1.** Level of service classes for vehicles at signalized intersections [1].

Delay Per Vehicle (sec/veh)	Level of Service Due To Volume-Capacity Ratio	
	$\leq 1$	$> 1$
$\leq 10$	A	F
$> 10-20$	B	F
$> 20-35$	C	F
$> 35-55$	D	F
$> 55-80$	E	F
$> 80$	F	F

The most preferred operation modes for signalized intersections are pre-timed and actuated modes [3]. Information for the modes (methods) used for the operation of traffic signalization systems are described below.

### 3.1. Pre-Timed Traffic Signalization Systems

Cycle lengths and phase timings are calculated and used as fixed timings for the pre-timed traffic signalization systems [3]. The right of way is provided one by one with the time programs prepared before for both vehicle and pedestrian, which are approaching the intersection from different directions. The timings of passing (green times) to be given to each traffic flow approaching the intersection from various directions and the ratio of these timings to each other are determined according to the predetermined traffic volumes. Therefore, in order for this system to be successful, it is necessary to make as many and precious traffic counts as possible.

Traffic flows in almost every intersection show different characteristics at different times of the day. In a pre-timed signalization system, it is aimed to arrange the traffic flow in the most appropriate way by applying some individual programs but signal timings are still fixed for each program that change automatically at certain times of the day like peak or off-peak periods in accordance with different traffic flow characteristics [4].

In the case of a very small number of pedestrians at a signalized intersection, the disuse of a pedestrian button especially for intersections operated by a pre-timed system, significantly affects the mobility of the vehicles. Therefore, some pedestrian groups have a continuous red light signal, especially at some pre-timed intersections, so long as there is no demand from pedestrians to prevent time loss and reduce delays [7].

The major shortcomings of pre-timed signalization systems are as follows:

- a) Traffic volumes contain certain periods of the day (usually peak hours)
- b) When traffic volumes change, congestion or idle capacity occurs at the intersection.
- c) Saturated flow is generally based on assumption and if not correctly estimated, the intersection capacity cannot be sufficiently utilized.
- d) The mistakes in phase number and orders negatively affect system performance, increase delay and decrease capacity.

Usually the characteristics of the traffic flows at weekends and the characteristics of traffic flows on normal working days are also different. Considering these differences, a pre-timed signalization system needs to be operated with different programs on holidays.

The biggest drawback of the pre-timed signalization systems is that traffic flows generally do not meet the average values used in the project and cause unnecessary waiting times and losses at the intersections. In order to reduce the effect of this drawback as much as possible, it is necessary to keep an intersection operated with a pre-timed signalization system under control, which is not a simple method at the point of application [5].

### 3.2. Semi-Actuated Traffic Signalization Systems

A dynamic control is applied for actuated signalization systems in accordance with vehicle and pedestrian traffic flows, which are changeable at different times of the day [3]. In actuated signalization systems, right of way, sequence of passage and timings for vehicles, are regulated automatically according to the traffic demands and densities determined by the detectors [5].

Considering that traffic flows are not constant throughout the day, a dynamic control system or an actuated traffic control system is preferable when it is considered that there are variable traffic volumes at different times of the day, and it would be more accurate than using a pre-timed signalization system [3]. Due to the dynamic nature of traffic flows, inadequate observations, insufficient number of programs, excessive delay for vehicles in the side road and the inability of pedestrians to use the road, actuated traffic control systems are needed to be used instead of pre-timed control systems.

There are two important parameters for actuated traffic control systems [4]:

**Demand:** No green light is signalled to the relevant traffic flow (except minimum green time) unless a demand is received from the detectors.

**Expansion Time:** In accordance with the warning received from the detector, the green signal time is extended up to the maximum value with a gap time determined before.

Actuated traffic control system is generally implemented in two ways as semi-actuated traffic signalization systems and fully actuated traffic signalization systems [3].

In the semi-actuated traffic signalization systems, warnings are accepted for some of the intersection approaches, not for all [3]. The green light signal is continuously given to the flows on the main road and is not given to the other flows (any of the secondary approaches or turning flows) unless a warning request is received from them [4]. In other words, for the semi-actuated signalization systems, the traffic warnings at the intersections are taken from some of the approach directions and the right of way is adjusted according to the traffic requests [3].

This system should be preferred if at least one of the following conditions occurs:

- a) The ratio of secondary road traffic volume to main road traffic volume is generally 1/8 or smaller; or if secondary road traffic demand is high only during peak hours.
- b) There is a difference of 30 km/h or more for 85% of approaching speeds between the main road traffic and secondary road traffic.
- c) The level of services for the main road traffic the secondary road traffic are very different.
- d) Priority for accident criteria for the establishment of a signalization facility.

### 3.3. Fully Actuated Traffic Signalization Systems

For fully actuated traffic signalization systems, continuous traffic demands are received from all of the approaches and right of way, sequence of passage and timings for vehicles, are regulated automatically according to the traffic demands and densities determined by the detectors [3]. Fully actuated traffic signalization systems are one of the most ideal systems that reduce total delays to a minimum level since detector data for all flows are considered [4].

This system should be preferred if at least one of the following conditions occurs [5]:

- a) If the total traffic flow at the intersection is low.
- b) If the traffic flows in the intersection are not balanced so as to be expressed in average values.
- c) If traffic flows in the intersection show an increase or decrease in short intervals.

The demand for green time in fully actuated signalization systems is determined by the detector warning of the conflicting traffic flow during its red period. Initially, the appropriate minimum green time is predetermined and adjusted within the junction control device. The appropriate minimum green time is usually adjusted to be sufficient for the number of vehicles waiting between the stop line and the vehicle detector. Each additional vehicle, which stimulates the detector during the green time, calls for a pre-defined green time extension for a vehicle. This extension time is applied from the minimum green time to the maximum green time, which are pre-determined in the controller [3].

The disadvantages of fully actuated signalization traffic systems are as follows [4]:

- a) The system works like a pre-timed signalization system under over saturated cases.
- b) Accidents can be seen if signal arrangement is not performed well in dilemma zones.
- c) The system may crash due to detector breakdowns.
- d) Not advantageous in non-variable traffic conditions.

### **3.4. Adaptive Traffic Signalization Systems**

Adaptive traffic signalization systems are one of the most advanced and complex traffic signal control systems available today. These systems dynamically create the best signal timings with the help of a central computer [4]. This system is especially preferred when the demand is high and time schedules need to be changed frequently.

Some basic algorithms on which adaptive signalization systems are based on are as followed [4]:

- a) Mathematical optimization algorithms
- b) Intuitive algorithms
- c) Artificial intelligence techniques (genetic algorithm, fuzzy logic, artificial neural networks, etc.)

Up-to-date equipment used in the implementation of adaptive signalization systems are generally loop detectors, wireless sensors and traffic cameras. Loop detectors are the most preferred among these detectors. However, these and other similar detectors remain weak because they can only obtain the presence and absence information of the vehicles. In order to develop the adaptive algorithms used today, the trend towards detector technologies, where data such as instantaneous traffic volume, position of vehicles and speed information can be provided, increases day by day [9].

In addition, important studies are carried out on the integration of intercommunication technologies and adaptive signalization systems, which are also a current issue [10].

### **3.5. Isolated Traffic Signalization Systems**

Isolated traffic signalization systems are systems that do not have connection with any other traffic signalization systems and do not affect any other traffic signalization systems [4]. In other words, they are signalization systems that do not have any relation with other systems and operate separately [3].

An isolated signalization system can be implemented in four different ways [5]:

- a) As a pre-timed signalization system.

- b) As a semi-actuated signalization system.
- c) As a fully actuated signalization system.
- d) As an adaptive signalization system.

### **3.6. Coordinated (Green Wave) Traffic Signalization Systems**

Coordinated traffic signalization systems are signalization systems that enable at least two intersections to be operated with a connection to each other on the same road [3]. In another saying, at two or more intersections where the main flows are very close to each other, it is the interconnection of the signalization facilities at the intersections in order to reduce delays and eliminate frequent stops and take-offs. Coordinated systems are usually arranged to pass the highest possible number of vehicles without stopping by providing adequate access to flows on the main road. While coordinated systems are primarily applied for main traffic flow, in some cases the possibilities of minimizing the total delay in all directions are also investigated. Coordinated systems can also be arranged as computer-controlled for all flows of a road network which has close signalized intersections [4].

In order to establish coordination between two intersections, the traffic flow between the two intersections must not be in randomly distributed groups. If the distance between the two signalized intersections is less than 750 meters, it is necessary to establish a coordination between these intersections as wave movements will not be distorted. Whereas coordinated systems can also be established between more remote intersections, its success depends on the possibility of keeping vehicle speeds at the desired order to ensure that wave motion is not disturbed [5].

Said coordination systems are used to reduce the delays between intersections on the same arteria or to establish a green wave to perform an optimal operating system. However, if the same principle is applied for traffic flows on many different directions, it is not possible to reach a solution by establishing a simple coordination system due to the intersections [4].

A coordinated signalization system can also be implemented in four different ways, such as pre-timed, semi-actuated, fully actuated and adaptive signalization systems, as in isolated signalization systems [5].

## **4. CASE STUDY for HACIOSMAN ARTERIAL in ISTANBUL**

In this part of the study, an optimization and simulation study will be carried out for the three signalized intersections in Istanbul Haciosman arterial. Primarily the method to be followed in the study will be explained briefly. Then some detailed information about the data to be used and the calibration of the micro simulation model to be developed for the study will be given. After that, six different scenarios will be developed for the three signalized intersections in the Istanbul Haciosman arterial by using the mentioned signal operation modes. Then some detailed information will be shared about optimization and simulation studies. Also a cost study was conducted by using some kind of growth factors for traffic volumes at 21056 – Maslak Acibadem Intersection for evening peak hours. It is aimed to investigate the feasibility of traffic sensor usage under oversaturated traffic conditions. Finally the results will be discussed.

### **4.1. Methodology**

The main issue of this study is to minimize the delays for Istanbul Haciosman arterial and three intersections on this arterial. Firstly some data such as traffic counts, geometry of intersections, circulation of traffic and current signal timings will be compiled for use in Synchro Studio which is one of the micro-scale traffic simulation programs. The micro simulation model will be developed and calibrated by using these data. Then six different scenarios will be developed for three signalized intersections in the Istanbul Haciosman arterial by using the

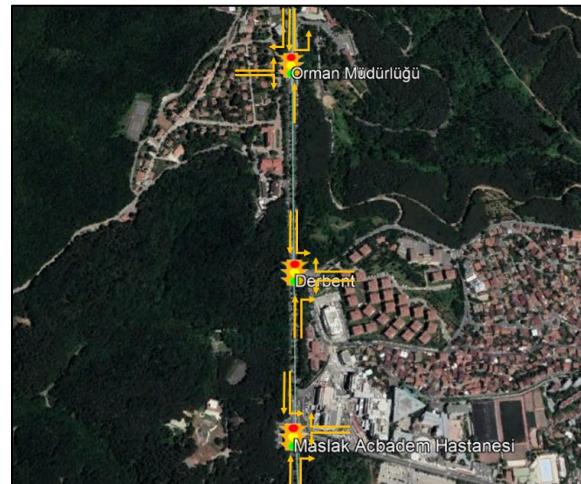
mentioned signal operation modes. Afterwards all of the scenarios will be optimized and simulated by using Synchro Studio. Finally some results such as level of services, delays and cycle lengths for each scenario will be obtained and compared.

Detailed information about all these steps mentioned for the methodology to be followed in this study is given below.

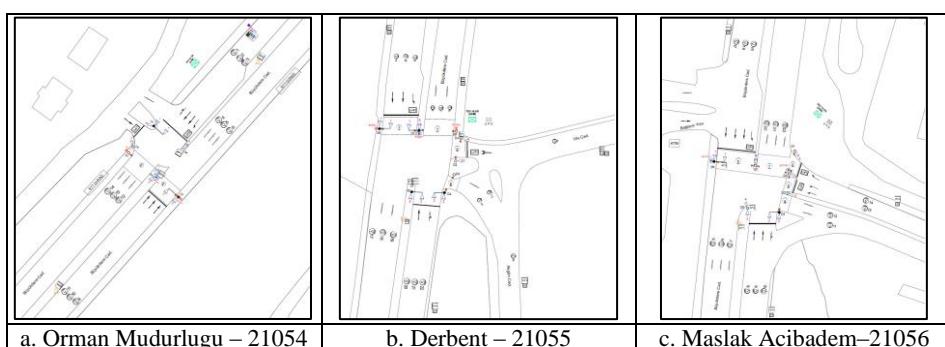
#### 4.2. Data Collection and Calibration

For the study, some data such as traffic counts, geometry of intersections, circulation of traffic and current signal timings has been collected. In this part, these data, which will be used to develop and calibrate the micro simulation model of Istanbul Haciosman arterial, will be explained in details.

First, there are three signalized intersections on the arterial as mentioned before. The names of them are Orman Mudurlugu, Derbent and Maslak Acibadem. They are coded with some numbers as 21054, 21055 and 21056 respectively. The circulation of traffic for each intersection and total arterial is shown in Figure 2. The geometry of intersections are shown in Figure 3 as well. These data are important while developing and calibrating the micro simulation model of the arterial.



**Figure 2.** Circulation of Traffic



**Figure 3.** Geometry of Intersections

Then, traffic count values for these three intersections were obtained for three different Fridays as a peak day in a row from the related detectors on the field. Hourly traffic volumes were obtained for each intersection and traffic flow by processing the raw data for each Friday. After that the average of volumes for each flow have been calculated and used as hourly average traffic counts for each flow for peak and off-peak periods.

A micro traffic simulation model has been developed and calibrated by using these data and current signal timings as well. In the current case, semi actuated and isolated signal operation modes for all of the intersections have been preferred. Micro traffic simulation program called Synchro Studio has been used for modelling. A view from the model developed for Haciosman arterial has been shown in Figure 4.



**Figure 4.** Micro Simulation Model View of Istanbul Haciosman Arterial

#### 4.3. Scenarios

In this part six different scenarios will be developed for the three signalized intersections in Istanbul Haciosman arterial by using the mentioned signal operation modes to be compared. These scenarios are:

- i. Pretimed-Isolated
- ii. Pretimed-Coordinated
- iii. Semi Actuated-Isolated
- iv. Semi Actuated-Coordinated
- v. Fully Actuated-Isolated
- vi. Fully Actuated-Coordinated

These scenarios are applied to the models prepared separately, and the studies on these scenarios are mentioned below. Finally a feasibility study for usage of traffic sensors under oversaturated traffic conditions have been performed as well.

#### 4.4. Optimization and Simulation Studies

In this part of the study pre-defined 21 different scenarios and also the current case has been simulated and optimized separately. Each of scenarios and the current case all includes three different files for morning peak, evening peak and off peak periods. Some results such as level of services, delays and cycle lengths for these 21 different options have been obtained and compared below.

#### 4.5. Discussions

As mentioned before, some results related with performance criteria such as level of services, delays and cycle lengths for the 21 different options mentioned before have been obtained and compared. The comparisons for each intersection is shown in Table 2, Table 3 and Table 4 in details.

**Table 2.** Performance of Orman Mudurlugu – 21054 Intersection

Criteria	Time of Day	Current Case	Scenario					
			1	2	3	4	5	6
LOS	Morning Peak	F	F	F	F	F	F	F
	Off Peak	F	F	D	E	C	D	C
	Evening Peak	D	F	D	E	C	D	C
Delays (sec.)	Morning Peak	174,1	198,5	140,4	179,7	127,3	149,8	124,9
	Off Peak	80,8	89,7	39,3	66,2	31,2	51,7	29,1
	Evening Peak	50,3	90,8	38,7	63,4	34,9	49,1	30,3
Cycle Lengths (sec.)	Morning Peak	230	150	250	150	245	200	235
	Off Peak	165	150	250	150	235	185	245
	Evening Peak	240	150	250	150	210	200	230

Table 2 shows the analysis results of each scenario for 21054 – Orman Mudurlugu intersection. According to the results, delay value per vehicle is 174.1 seconds for morning peak, 80.8 seconds for off-peak and 50.3 seconds for evening peak in the current case. In the first scenario, which is pretimed-isolated signal operation mode, it is seen that the delay values increase to 198.5, 89.7 and 90.8 seconds respectively. In the third scenario, which is semi actuated-isolated signal operation mode, it is seen that the delay values decrease to 179.7, 66.2 and 63.4 seconds respectively. In the fifth scenario, which is fully actuated-isolated signal operation mode, it is seen that the delay values decrease to 149.8, 51.7 and 49.1 seconds respectively.

Compared with the current case, in the second scenario, which is pretimed-coordinated signal operation mode, it is seen that the delay values decrease to 140.4, 39.3 and 38.7 seconds respectively. In the fourth scenario, which is semi actuated-coordinated signal operation mode, it is seen that the delay values decrease to 127.3, 31.2 and 34.9 seconds respectively. In the sixth scenario, which is fully actuated-coordinated signal operation mode, it is seen that the delay values decrease to 124.9, 29.1 and 30.3 seconds respectively.

**Table 3.** Performance of Derbent – 21055 Intersection

Criteria	Time of Day	Current Case	Scenario					
			1	2	3	4	5	6
LOS	Morning Peak	C	D	B	C	B	C	B
	Off Peak	C	C	B	C	B	C	B
	Evening Peak	D	D	C	D	C	C	B
Delays (sec.)	Morning Peak	30	47,4	18,2	34	18,9	24,7	18,3
	Off Peak	23,9	31	15,6	27,8	16,5	22,3	14,3
	Evening Peak	44,3	40,5	26,6	37,2	20,4	33,4	19,3
Cycle Lengths (sec.)	Morning Peak	230	90	250	90	245	120	235
	Off Peak	165	80	250	65	235	85	245
	Evening Peak	240	120	250	120	210	125	230

Table 3 shows the analysis results of each scenario for 21055 – Derbent intersection. According to the results, delay value per vehicle is 30 seconds for morning peak, 23.9 seconds for off-peak and 44.3 seconds for evening peak in the current case. In the first scenario, which is pretimed-isolated signal operation mode, it is seen that the delay values increase to 47.4, and 31 seconds for the morning peak and off peak hours respectively, while the delay values decrease to 40.5 seconds for the evening peak. In the third scenario, which is semi actuated-isolated signal

operation mode, it is seen that the delay values decrease to 34, 27.8 and 37.2 seconds respectively. In the fifth scenario, which is fully actuated-isolated signal operation mode, it is seen that the delay values decrease to 24.7, 22.3 and 33.4 seconds respectively.

Compared with the current case, in the second scenario, which is pretimed-coordinated signal operation mode, it is seen that the delay values decrease to 18.2, 15.6 and 26.6 seconds respectively. In the fourth scenario, which is semi actuated-coordinated signal operation mode, it is seen that the delay values increase to 18.9 and 16.5 seconds for the morning peak and off peak hours respectively, while decreases to 20.4 seconds for the evening peak. In the sixth scenario, which is fully actuated-coordinated signal operation mode, it is seen that the delay values decrease to 18.3, 14.3 and 19.3 seconds respectively.

**Table 4.** Performance of Maslak Acibadem – 21056 Intersection

Criteria	Time of Day	Current Case	Scenario					
			1	2	3	4	5	6
LOS	<b>Morning Peak</b>	D	D	C	D	C	C	C
	<b>Off Peak</b>	D	D	C	C	C	C	C
	<b>Evening Peak</b>	F	E	E	E	E	E	E
Delays (sec.)	<b>Morning Peak</b>	45,5	39,9	25,1	35,8	25,2	31,9	22,5
	<b>Off Peak</b>	35,8	36,2	28	28,5	26,2	24,2	24,8
	<b>Evening Peak</b>	83,1	75,9	67,1	63,9	66,3	55,4	63,1
Cycle Lengths (sec.)	<b>Morning Peak</b>	230	120	250	125	245	130	235
	<b>Off Peak</b>	165	110	250	115	235	120	245
	<b>Evening Peak</b>	240	150	250	160	210	180	230

Table 4 shows the analysis results of each scenario for 21056 – Maslak Acibadem intersection. According to the results, delay value per vehicle is 45.5 seconds for morning peak, 35.8 seconds for off-peak and 83.1 seconds for evening peak in the current case. In the first scenario, which is pretimed-isolated signal operation mode, it is seen that the delay values decrease to 39.9, and 75.9 seconds for the morning peak and evening peak hours respectively, while the delay values increase to 36.2 seconds for the off peak. In the third scenario, which is semi actuated-isolated signal operation mode, it is seen that the delay values decrease to 35.8, 28.5 and 63.9 seconds respectively. In the fifth scenario, which is fully actuated-isolated signal operation mode, it is seen that the delay values decrease to 31.9, 24.2 and 55.4 seconds respectively.

Compared with the current case, in the second scenario, which is pretimed-coordinated signal operation mode, it is seen that the delay values decrease to 25.1, 28 and 67.1 seconds respectively. In the fourth scenario, which is semi actuated-coordinated signal operation mode, it is seen that the delay values decrease to 26.2 and 66.3 seconds for the off peak and evening peak hours respectively, while the delay values increase to 25.2 seconds for the morning peak. In the sixth scenario, which is fully actuated-coordinated signal operation mode, it is seen that the delay values decrease to 22.5, 24.8 and 63.1 seconds respectively.

Finally a cost study was conducted by using some kind of growth factors which are %10, %20, %30, %40 and %50 for traffic volumes at 21056 – Maslak Acibadem Intersection for evening peak hours to investigate the feasibility of traffic sensors usage under oversaturated traffic flows. The results of this study have been shown in Table 5.

**Table 5.** Performance of Maslak Acibadem – 21056 with Growth Traffic Volumes

		<b>LOS</b>	<b>Delays (sec.)</b>	<b>Cycle Lengths (sec.)</b>	<b>ICU (%)</b>
<b>Growth Factor %0</b>	<b>Pretimed</b>	E	75,9	150	103,3
	<b>Actuated</b>	E	55,4	180	103,3
<b>Growth Factor %10</b>	<b>Pretimed</b>	F	115,9	150	112
	<b>Actuated</b>	F	90,8	175	112
<b>Growth Factor %20</b>	<b>Pretimed</b>	F	148,5	150	120,8
	<b>Actuated</b>	F	135	160	120,8
<b>Growth Factor %30</b>	<b>Pretimed</b>	F	191,3	150	129,5
	<b>Actuated</b>	F	183,9	150	129,5
<b>Growth Factor %40</b>	<b>Pretimed</b>	F	224,3	150	138,3
	<b>Actuated</b>	F	220,1	150	138,3
<b>Growth Factor %50</b>	<b>Pretimed</b>	F	264,8	150	147
	<b>Actuated</b>	F	262,8	150	147

According to the analysis results shown in Table 5, it is possible to say that delay values per vehicle is 75.9 seconds for pretimed signal operations and 55.4 seconds for actuated signal operations if the growth factor of traffic volumes is %0, while they are 115.9 seconds for pretimed signal operations and 90.8 seconds for actuated signal operations if the growth factor of traffic volumes is %10. Delay values per vehicle is 148.5 seconds for pretimed signal operations and 135 seconds for actuated signal operations if the growth factor of traffic volumes is %20, while they are 191.3 seconds for pretimed signal operations and 183.9 seconds for actuated signal operations if the growth factor of traffic volumes is %30. Finally the delay values per vehicle is 224.3 seconds for pretimed signal operations and 220.1 seconds for actuated signal operations if the growth factor of traffic volumes is %40, while they are 264.8 seconds for pretimed signal operations and 262.8 seconds for actuated signal operations if the growth factor of traffic volumes is %50.

## 5. CONCLUSION

For Istanbul Haciosman arterial, the best performance for the intersection 21054 – Orman Mudurlugu for all of the time intervals (morning peak, off peak and evening peak hours) occurs in Scenario 6 which is fully actuated and coordinated operation mode as shown in Table 2. Similarly for the intersection 21055 – Derbent the best performance for both off peak and evening peak occurs in Scenario 6. For morning peak hours, the best solution for this intersection is Scenario 2 which is pretimed and coordinated operation mode with a very close value to Scenario 6 as shown in Table 3. The best performance for the intersection 21056 – Maslak Acibadem for both morning and evening peak occurs in Scenario 6 as well, while the best solution for this intersection is Scenario 5, which is fully actuated and isolated operation mode for off peak hours with a very close value to Scenario 6 as shown in Table 4.

As mentioned above, fully actuated and coordinated systems have often the best delay values, but not always. The choose of master intersection for the coordination is the main reason of this situation. 21054 – Derbent Intersection is the master intersection for Haciosman arterial due to the level of service and demand values. The reason why Scenario 6 for 21055 – Derbent Intersection at morning peak and 21056 – Maslak Acibadem Intersection at off peak hours is not the best solution is because of the master intersection for the coordination is 21054 – Derbent Intersection. When coordination evaluated, total delay values for the arterial (not for intersections locally) is important and sometimes even delay values for one or more of the intersections increase, it is possible for delay values of total arterial to decrease. The situation of Derbent Intersection at

morning peak and Maslak Acibadem Intersection at off peak hours is an example for this case. Basically, the delay values for these two intersections increase but the delay values for the master intersection and total arterial decrease much more in numbers.

According to the analysis results shown in Table 5, it is possible to say that delay values per vehicle increase as growth factor of traffic volumes increase as expected. When the growth factor is increased, the difference between delay values for pretimed and actuated systems are decreased as well. According to the results shown in Table 5, it is also possible to say that, using traffic sensors for 21056 – Maslak Acibadem Intersection at evening peak is not feasible after the growth factor reaches to %30 or %40. As shown in Table 5, the difference between delay values are very close to each other after the increment of traffic volumes for a level of %30-%40.

As a result, pre-timed signalization systems are the poorest operating systems for signalized intersections when the delay values are compared. Besides, the best operating systems are fully actuated ones. Semi actuated signalization systems are better than pretimed ones but worse than fully actuated systems due to delay values per vehicle at examined intersections. By the way, coordinated systems have better results than isolated ones in general.

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