Scientific Journal of Silesian University of Technology. Series Transport
Zeszyty Naukowe Politechniki Śląskiej. Seria Transport

Volume 121 **2023**

p-ISSN: 0209-3324

e-ISSN: 2450-1549

DOI: https://doi.org/10.20858/sjsutst.2023.121.1

Journal homepage: http://sjsutst.polsl.pl

Article citation information:
Aydin, M.M., Potoglou, D., Cipcigan, L. Working principle and performance evolution of camera-based intelligent signalized intersections: Samsun city, Türkiye example. *Scientific Journal of Silesian University of Technology. Series Transport*. 2023, **121**, 5-17.
ISSN: 0209-3324. DOI: https://doi.org/10.20858/sjsutst.2023.121.1.

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WORKING PRINCIPLE AND PERFORMANCE EVOLUTION OF CAMERA-BASED INTELLIGENT SIGNALIZED INTERSECTIONS: SAMSUN CITY, TÜRKIYE EXAMPLE

Summary. In the current literature, it is clearly seen that most of the traffic chaos is generally observed at intersections of the urban roads in cities. On the other hand, many current traffic studies and research prove that fixed-time signalized intersections cannot have a good ability to control and manage current traffic flow at signalized intersection legs. For this aim, intelligent intersections were developed and started to be used in many cities all over the world in the last decade. These new intelligent intersection systems suggest dynamic signal times for all intersection legs by using real-time measured traffic data. These systems generally use cameras or loop detectors, which are located in the proper places on a signalized intersection leg and record vehicle movements. Within the scope of this study, a performance comparison was made for before and after the camera-based intelligent intersection applications at three isolated pilot signalized intersections within the scope of the "Smart City Traffic Safety" project, which is one of the largest Intelligent Transportation System projects in Turkey. After the system was activated, it was observed that the drivers had impatient behaviors in the beginning

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and had difficulty getting used to these new systems. After the signal cycle was regulated with the learning of artificial intelligence, it was seen that the drivers had more patience and more observant behaviors. It was also obtained from the analysis results that these new intelligent systems resulted in an average 16% decrease in control delays and a 20% decrease in vehicle speeds.

Keywords: intelligent intersection, traffic chaos, control delay, dynamic signal timing, urban roads

1. INTRODUCTION

Intelligent signalized intersections (ISIs) will play an important role in traffic management and the improvement of delays, vehicle speeds and emissions by ensuring road safety at signalized intersections [1]. These systems can also be named "smart signalized intersections, traffic-actuated signalized intersections," and camera-based or sensor-based ISIs. They can obtain data from the cameras or sensors, process the data by taking advantage of low-atency, high-bandwidth communications, detect and track objects, and provide intelligent feedback and input to the main control and operating systems. These systems have a key role in smart cities. The connection and collection among intersections, roads and corresponding vehicle and pedestrian traffic fully define the real-time dynamics of a smart city [2-4]. ISIs will be at the core of artificial intelligence-powered traffic control and management systems for the future of cities. The World Economic Forum 2019 reported that big cities will double the number of vehicles up to 2040. This report led to the conclusion that traffic related problems with road flow tend to increase, and smart systems are a possible solution to these problems. They could be effective in the creation of mechanisms that allow current cities to be “smarter” than they are now. Thus, many countries have started to transform their cities into smart cities. There has been a big interest among the national road authorities in promoting research focused on transformation [5]. Especially, developing intelligent traffic light systems has an important role in this transformation because they have many important points for vehicle connection and traffic chaos [6, 7].

The current number of traffic cameras in all cities is estimated to be billions, and they could be a great help in developing ISIs, since they would provide various information from the control system, which would include the detection and counting of vehicles and pedestrians in the different study areas. Thus, many studies have been conducted to obtain signalized intersection traffic data and propose flexible and dynamic traffic light times [8]. For this purpose, the first video image processing system, called the Spatial Image Processing Traffic Flow Sensor, was developed by [9] to detect traffic queue length on roads. Then, [10] developed image processing systems to measure traffic parameters such as volume, speed, vehicle length, and queue length. In another study, [11] started to use virtual loops to measure various parameters in traffic flows. In these loops, the size and position of each loop can be adjusted by users to collect proper volume, speed, occupancy, and vehicle classification data. In their study, [8] also proposed a video image processing system to determine the traffic signal cycle failure by tracking the queue formation to increase the performance of the current traffic system. In a similar vehicle tracking research [12], suggested a new method to track vehicles by matching different regions with vehicles via video recordings. The research aims to uncover vehicle attributes, such as the geographical location, length, and speed, through the collection of images by a properly calibrated and high-definition traffic camera. In a conducted study of [13], average stop number and control delay of vehicles were tried to be estimated by using the image analysis technique (IAT). The total control delay was aimed at being obtained by adding all the delays of stopped vehicles in an examined time interval.

Roadside vehicle and environment monitoring systems for signalized intersections are constant platforms, which generally consist of pole-mounted or standard cameras placed in high locations, and are connected to a control center or a device [14, 15]. Today, camera systems are extremely cheap, small and smarter than the previous [16]. In addition, the increase in processor power as well as the emergence of a new generation of embedded architectures which allow real-time site applications have spawned a huge interest in camera-based detection and tracking systems in the cities [17]. Especially for signalized intersections, most of these camera-based traffic systems require one or more traffic cameras to be mounted at highly elevated locations. In the current site applications, single-camera-based traffic systems are mostly preferred to monitor signalized intersections. Most of them work on multiple traffic camera-based systems, and each camera in the system works independently, and then they perform a high-level fusion for the observation and data collection from the examined intersections [18, 19]. In addition, to get more accurate results from the systems, important pre-processing steps of the systems such as the calibration of cameras, are necessary before operating them.

The latest developments and studies on intelligent transportation systems (ITS) clearly show that the utilization of IT systems is of great importance to making cities “smarter”. Thus, many cities around the world have started to apply to these systems to get smart city titles, give good service to their citizens, and save humans and the world. In its project, Samsun Metropolitan Municipality (SMM) has also started to apply one of the biggest ITS project in Turkey. Intelligent Signalized Intersections (ISIs) are the most important part of this project. In this study, used ISI systems and the transformation process are introduced in detail with all their properties. Then, the completed six ISIs performance evaluation analysis results are shared. Results indicate that ISIs have a great effect on the transformation of cities into smarter cities, and they have a positive effect on reducing traffic chaos, controlling delays, vehicle speed and emissions at intersections, which have the highest complexity in urban road networks.

2. SMART CITY TRAFFIC SAFETY (SCTS) PROJECT

“Smart City Traffic Safety Project” is a candidate project to become the biggest Intelligent Transportation System (ITS) project in Turkey. It is conducted with the collaboration of Samsun Metropolitan Municipality (SMM) and ASELSAN for 2021 summer. The project aims to transform 72 fixed-time or non-signalized intersections into intelligent signalized intersections, average speed detection system in main corridors, parking violation detection system in roadside parking areas, red light violation detection system in sections with signalized lights, and initially 20 electric buses into public transportation hubs. Thus, the SCTS project can be named one of the biggest ITS project in Turkey.

3. INTELLIGENT SIGNALIZED INTERSECTIONS (ISI) APPLICATIONS

As a part of the implementation of the project, 72 ISI will be implemented to manage traffic and reduce air pollution throughout the city by decreasing waiting times and delays at signalized intersections. The locations of all intelligent signalized intersections are given in Fig. 1. Geometric arrangements, infrastructure, and installation processes for all digital equipment started in August 2021, and are planned to finish in August 2023. Real site before-and-after transformation and construction images for some ISIs are also given in Fig. 2.

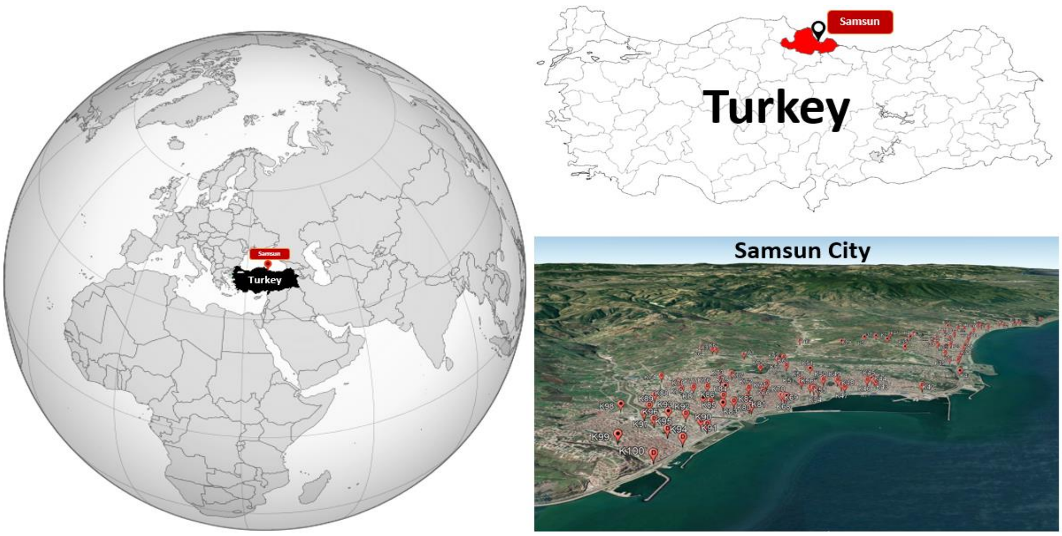


Fig. 1. Locations of 72 intelligent signalized intersections at urban roads in Samsun/Türkiye

(a) (b)

(c) (d)

Fig. 2. Real site images for (a-b) before and after transformation and (c-d) construction duration

All work packages and applied steps for the transformation of all these intersections can be summarized as given in the flowchart below (Fig. 3).

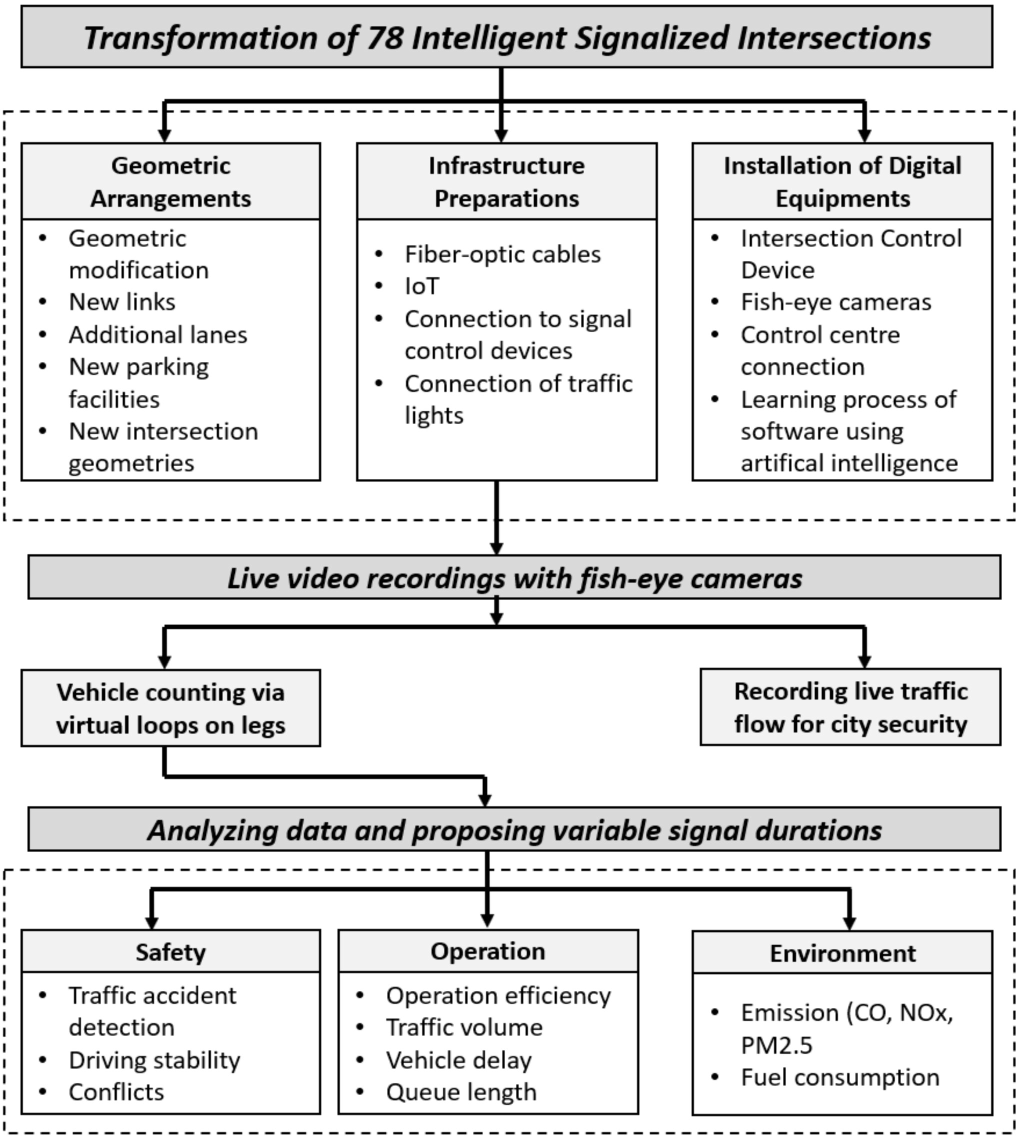


Fig. 3. Work packages and steps for the transformation of 78 intersections

3.1. Definition of System Properties and Working Principles

Intelligent signalized intersection (ISI) systems with cameras are an instant traffic control and operating system. It includes computer-based vision solutions. This system mainly uses a single fish-eye camera. With the help of the locations of cameras, this system can obtain various traffic-related data, such as entry and exit directions of vehicles, vehicle classes, average speed, etc. After the data collection process, the system process obtained data, and it controls the signalized intersection instantly and regularly in real time. The ISI system with traffic cameras manages the total cycle time of the signalized intersections by regulating green durations at intersection legs in an adaptive manner. It includes a fully adaptive analysis method which helps optimize traffic control in real time. Thus, camera-based intelligent signalized systems ensure high contributions to the economy via reducing fuel consumption of vehicles; to human health by reducing gas emissions; and to driver psychology by reducing vehicle delays and total travel time in traffic. ISI systems also include an intelligent traffic controller (ITC) device, an image processing device (IPD), fish-eye camera, a camera pole (the height of the unit may show changes), and analysis software.

a-) Intelligent Traffic Controller (TCI) Device. It helps to decide colour of the lights in real time. This device includes a real-time decision-making mechanism, different control and protection plans, a mathematical model and algorithms, and artificial intelligence. This device also uses different traffic sensors and detectors that can be controlled from the main traffic control room (Fig. 4a).

b-) Image Processing Device (IPD). This device supplies many traffic related factors by using image processing techniques through mathematical formulation and different algorithms. This device has the ability to detect and track moving and stopping vehicles. It can also count vehicles according to their types and determine the O-D matrix of vehicles using type classification, length-based classification, congestion-occupancy detection, and virtual pan-tilt-zoom properties (Fig. 4b).

c-) Fish-eye Camera. This type cameras generally have minimum 12-megapixel CMOS. and a 360-degree visual angle. Thus, they can complete intersection management in one lump. These cameras also have day and night properties, operation between -30°C and +60°C, high-resolution properties for video recordings.

d-) Camera Pole. In real-world applications, up to 18-meter poles for traffic cameras are used. Thus, they provide a good opportunity for the cameras to record real-site videos for the analysis (Fig. 4c).

e-) Developed Software for Virtual Loop Editing. In the ISI, developed software helps to determine the limits of loop regions. Thus, vehicles can be detected and tracked via image processing method. This software has user-friendly properties, and it supplies draw, edit, and apply options for virtual loops to the operators. Hence, operators can modify the loops according to their needs. Designed loops have different colours to define loops according to their properties. For example, red loops define entries at signalized intersections. Similarly, blue loops define exits at signalized intersections. After completing loop design, the developed software provides information regarding the real-time traffic data n which is obtained by the designed loops. The developed user interface of the software supplies more than 50 different regions to be drawn and edited for the signalized intersections. The installation and editing process of the regions by the user-friendly software is given in Fig. 4d.

f-) Analysis Software of the System. This developed software generates data for the applied intelligent signalized intersection control.

f.1-) Triggers on ISI Entering Lanes. In the developed software, the yellow regions are used to generate triggers before intersection entry. The software supplies easy drawing options for the yellow region. Thus, operators can easily control the duration of the lights for corresponding directions such as left turn, right turn, and straight ahead. On the other hand, the system can calculate the percentage of occupancy for each lane of the intersection. Thus, it gives important information on the entry movement of vehicles from each lane of the intersection (Fig. 4e).

f.2-) Triggers on ISI Inside Lanes. According to the developed software, there are two regions inside the intersections defined as red and blue. These regions are used to obtain necessary statistical data during vehicle entry and exit at the intersection. In the loop editing process, red regions should be drawn for all lanes separately. On the contrary, blue regions inside the intersection can also be drawn for the exit lanes separately. According to the working principle

of the software, all vehicles are tracked from the red regions (entry) to the inside (blue) regions. Hence, software can measure the vehicle numbers inside the intersection instantly, and it can also define their following routes. Thus, the system can determine the congestion at the signalized intersection. Additionally, triggers can be generated before entering and exiting the entry and exit lanes of the intersection or crossing predefined regions of the intersection, and this information can be used for management of the intersection and saving many statistical data. Thus, all these obtained data can be used for the future master traffic plans of the cities (Fig. 4f).
g-) Developed Reporting Software. In the ISI, reporting software is an essential step to understanding the application results. This software supplies the results in various digital formats. As known, the ISI system has vehicle tracking ability, and all obtained analysis results can be reported with the help of developed software, such as traffic volume, queue length, density distribution, vehicle classification (4 vehicle types), average speed and traffic volume using reporting software (Fig. 4f).

4. METHODOLOGY

4.1. Definition of System Properties and Working Principles

To evaluate the performance of camera-based intelligent signalized intersections at urban roads of Samsun city, total of six new ISIs were obtained from the reporting software. The locations of the examined ISIs are shown in Fig. 5.

As mentioned before, almost all intersections underwent geometric modification during the project. The previous geometric properties and new intersection design features of all these examined intersections are also seen in Fig. 6. The previous signalized intersection types and the new types of examined ISIs are also given in Table 1.

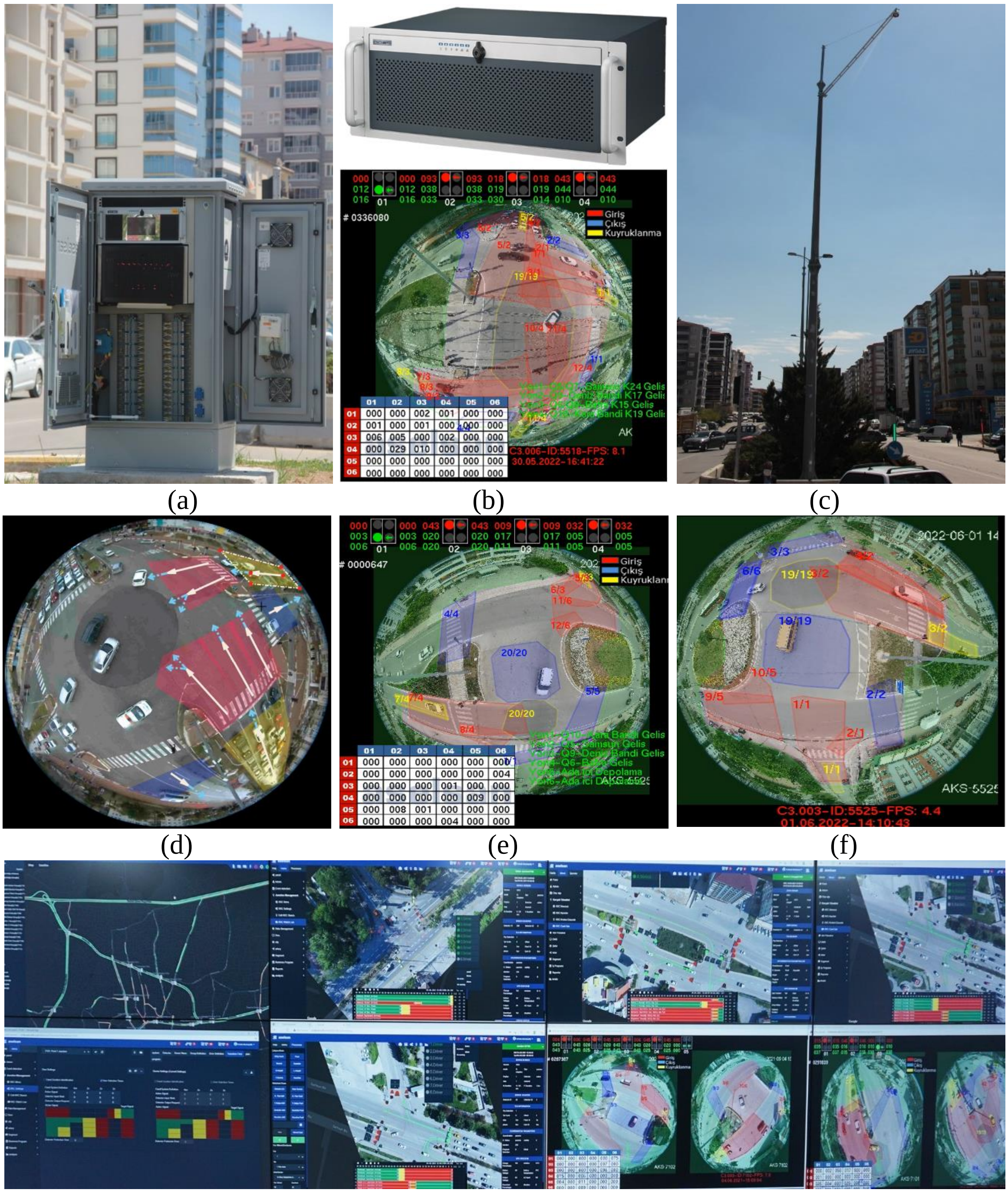
Tab. 1

Previous and new types of examined intersections

Inter. No	Previous Type	Current Type (ISI)	Average Daily Traffic (veh/day) *
1	4-leg signalized traffic circle	4-leg signalized	18567
2	4-leg signalized traffic circle	4-leg signalized	29645
3	4-leg signalized	4-leg signalized	30565
4	4-leg signalized traffic circle	4-leg signalized roundabout	55054
5	4-leg signalized traffic circle	4-leg signalized	43575
6	3-leg unsignalized roundabout	4-leg signalized roundabout	35972

* Data belongs to 2019-year real site measurements.

In the study, all vehicle data was obtained by counting the properties of the system software using the image processing method. All vehicle numbers were determined by the counting of fish-eye cameras' real-time recordings. During the counting process, vehicle types are classified in 4 groups: passenger cars, minibuses, buses/midibuses, and trucks/lorries by the system software using the image processing method.



(g)

Fig. 4. Real site images from the ISI system (a) ITC, (b) IPU, (c) Camera pole and Fish-eye camera, (d) Editing of virtual loops, (e) Triggers on intersection entering lanes, (f) Triggers inside Intersection and (g) Reporting of obtained data and findings [20]

Fig. 5**.** Locations of examined 6 ISIs on urban roads of Samsun city

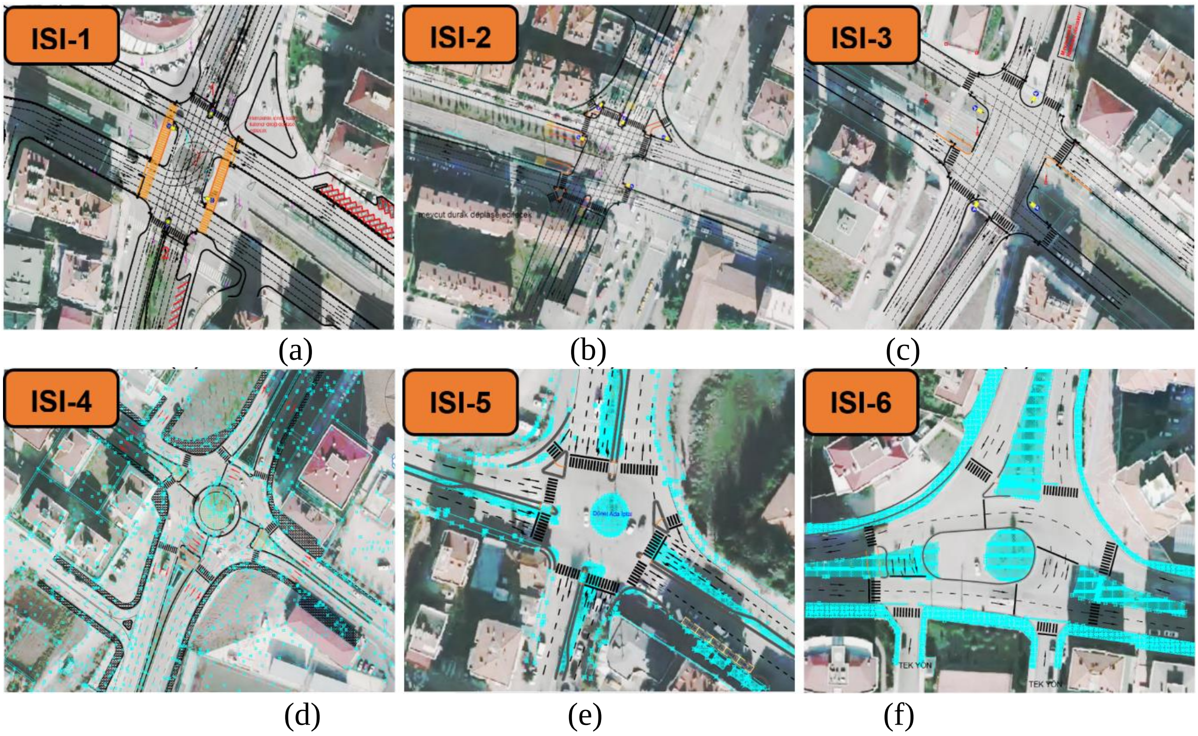


Fig. 6. Previous geometric properties and new intersections design features of examined 6 ISIs

4.2. Definition of System Properties and Working Principles

As can be seen from the descriptive statistical analysis in Table 2, the highest Average Daily Traffic (ADT) flow is obtained in ISI-4 and the lass is observed in ISI-1. Table 2 also shows that the most observed vehicle type was the passenger car and the least observed was the truck/lorry as expected on urban roads.

Tab. 2

Vehicle and traffic flow statistics for the examined 6ISIs

Intersect. No	**Vehicle Type**							
	Passenger Car		**Minibus**		**Bus/Midibus**		**Truck/Lorry**	
	ADT	**σ**	**ADT**	**σ**	**ADT**	**σ**	**ADT**	**σ**
1	15384	2022	2953	422	1139	117	1199	121
2	23599	1984	5066	428	1289	150	1093	187
3	22515	21557	7322	6748	1666	1749	1351	1448
4	45771	44299	7290	6795	3195	3824	1810	2333
5	22361	18618	12528	12528	8860	8611	1813	1793
6	22378	4055	7928	1308	5049	513	2454	467

ADT: Average Daily Traffic, σ: Standard Deviation, unit: Veh/Day for ADT and σ.

The given results in Table 3 were also calculated by the developed software in the system. From the analysis, changes (decrease) in control delays, speeds and emissions were also calculated by the system.

Tab. 3

Obtained results after the application of new intelligent intersection systems

Intersection No	**Decrease in**			
	Control Delays (sec.) (%)	**Average Speeds (km/h) (%)**	**CO_2 (gr)**	**PM10 (gr)**
1	11	14	415	602
2	20	22	886	905
3	16	19	845	867
4	22	25	3499	5176
5	14	17	876	859
6	12	15	869	843
Average ($\bar{X}$)	16	19	1232	1542

As can be seen from Table 3, changes for control delays, average vehicle speeds and emission values show differences at different ISIs. Traffic volume, driver characteristics and behaviors, vehicle types, and intersection types can show the most important parameters in these results. It can be seen from the table that the highest decrease in control delays is observed at ISI-4 and the least at ISI-1. Similar results are also obtained for average vehicle speeds in the same ISIs. These new intelligent systems resulted in an average 16% decrease in control delays and a 19% decrease in average vehicle speeds. It can also be seen from Table 3 that these new intersection management systems have an important role in reducing emissions at signalized intersections. These systems reduced an average of 1232 gr CO_2 and 1542 gr PM10 daily. It can be concluded that ISIs have a great effect on reducing traffic chaos, control delays, vehicle speed, and emissions.

5. CONCLUSIONS AND SUGGESTIONS

In the last decade, there has been a considerable increase in the application of Intelligent Signalized Intersections (ISIs). Performance of new ISIs plays a vital role in the safety and quality of travel on arterial networks and urban roads. On the other hand, the collection of intersection performance data, such as vehicle control delay and queue length, is a time-consuming and labour-intensive task. In this paper, new ISIs and the transformation of signalized intersections are introduced in detail. Then, a performance evaluation of the pilot new ISI applications on urban roads in Samsun City was made. Evaluation results indicated that these new intelligent systems resulted in an average 16% decrease in control delays and a 19% decrease in average vehicle speeds, and these results may vary according to intersection, driver, and vehicle characteristics. It is also determined from the results that these new intersection management systems have an important role in reducing emissions, which has a vital impact on climate change at signalized intersections. According to calculated results from the examined 6 new ISIs, transformation to intelligent intersections reduces on average 1232 gr CO_2 and 1542 gr PM10 daily. Thus, it can be clearly revealed that ISIs have a great effect on reducing traffic chaos, controlling delays, vehicle speeds, and emissions, as well as making cities “smarter”.

In this study, only completed 6 ISIs performance evaluation were made. Rest 72 ISIs transformation process still continues. It is thought that after the remaining systems are completed, there will be significant reductions in traffic chaos, control delays, vehicle speed and emissions throughout the city, the intersections and road networks in the entire city will work as a whole and integrated. Thus, citizens will face less complexity and emissions caused by city traffic.

Acknowledgements

This study was conducted under a research project titled “i-gCar4ITS: Innovative and Green Carrier Development for Intelligent Transportation System Applications” which was supported by the British Council. The authors would like to thank the British Council for this support. The authors also thanks Samsun Metropolitan Municipality, Ondokuz Mayıs University and Cardiff University for their partnerships and support.

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Received 25.06.2023; accepted in revised form 14.08.2023