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

Volume XXX **2023**

p-ISSN: 0209-3324

e-ISSN: 2450-1549

DOI: XXXXXXXXXXXXXXXXXXXXXXX

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

Article citation information:
Aydın, M., Potoglou, D., Cipcigan, L. Working Princible and Performance Evolution of Camera-based Intelligent Signalized Intersections: Samsun City, Türkiye Example. *Scientific Journal of Silesian University of Technology. Series Transport*. 2023, **XX**, XX-XX. ISSN: 0209-3324. DOI: https://doi.org/10.20858/sjsutst.2021.110.1. – 12-

Metin Mutlu AYDIN[1], Dimitris POTOGLOU[2], Liana CIPCIGAN[3]

WORKING PRINCIBLE 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 researches proved 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 use 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 to proper places on a signalized intersection leg and records vehicle movements. Within the scope of this study, a performance comparison was made for before and after the camera-based intelligent intersection

[1] Faculty of Engineering, Ondokuz Mayıs University, Kurupelit Kampüsü, 55217 Samsun, Turkey. E-mail: metinmutluaydin@gmail.com ORCID: https://orcid.org/0000-0001-9470-716X
[2] School of Geography and Planning, Cardiff University, CF10 3WA, Cardiff, United Kingdom. E-mail: potogloud@cardiff.ac.uk ORCID: https://orcid.org/0000-0003-3060-7674
[2] School of Engineering, Cardiff University, CF24 3AA, Cardiff, United Kingdom. E-mail: cipciganlm@cardiff.ac.uk ORCID: https://orcid.org/0000-0002-5015-3334

applications at three isolated pilot signalized intersections within the scope of the "Smart City Traffic Safety" project, which is one of the large is Intelligent Transportation System projects in Turkey. After the system was activated, it was observed that the drivers had impatient behaviors in the beginning and had difficulty in 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 patient and more observant behaviors. It was also obtained from the analysis results that these new intelligent systems resulted in average 16% decrease for control delays and %20 for 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 improvement on delays, vehicle speeds and emissions by supplying road safety at signalized intersections [1]. These systems can also be named as 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-latency high-bandwidth communications, and detect and track objects; and provide intelligent feedbacks and input to main control and operation 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]. ISIs will be at the core of an artificial intelligence powered traffic control and management system for the future of the cities. The world Economic Forum 2019 reported that big cities will double the number of vehicles up to 2040. This report led to deduce that the traffic related problems to road flow tend to increase and smart systems are a possible solution to these problems. They could be effective on the creation of mechanisms that allow current cities to be “smarter” than now. Thus, many countries have started to trans-form their cities to smart cities. There has been a big interest by the national road authorities in promoting research focused on transform in recent years [3]. Especially, developing intelligent traffic light systems has an important role in this transform because they have many important points for vehicle connection and traffic chaos [4].

Nowadays, there are billions of traffic cameras installed in all cities and they could result in a great benefit to develop ISIs because it would supply various data from the control system which would consist in the detection and counting of vehicles and pedestrians in the different study areas [5]. Thus, many researches have been con-ducted to obtain signalized intersection traffic data and propose flexible and dynamic traffic light times [6]. For this purpose, first video image processing, called Spatial Image Processing Traffic Flow Sensor, was developed by [7] to detect traffic queue length in roads. Then, [8] developed image processing systems to measure traffic parameters such as volume, speed, vehicle length, and queue length. In another study, [9] 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, [6] 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 study, [10] suggested a new method to track vehicles by matching different regions with vehicles via video recordings. In the study, vehicle parameters such as location, length, and vehicle speed can be obtained from captured images by a properly calibrated and high resolute traffic camera. In a conducted study of [11], average stop number and control delay of vehicle were tried to estimate by using image analysis technique (IAT). The total control delay was aimed to obtained by adding all the delays of stopped vehicle in an examined time interval.

Roadside vehicle and environment monitoring systems for signalized intersections are constant platforms which generally consist of in pole-mounted or standard cam-eras placed on high locations and they are connected to control center or a device [12-13]. In today, camera systems are extremely cheaper, smaller and smarter than the previous [14]. In addition, the increase on processors' power, as well as the emergence of new generation of embedded architectures which allow real-time site applications, have spawned a huge interest for camera-based detection and tracking systems in the cities [15]. Especially, most of these camera-based traffic systems require one or multiple traffic cameras to be mounted at highly elevated locations for signalized intersections. In the current site applications, single-camera-based traffic systems are mostly preferred to monitor signalized intersections. Most of them works 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 [16, 17]. In addition, to get more accurate results from the systems, important pre-processing steps of the systems such as calibration of cameras are necessary before operating all these systems.

Latest developments and studies on intelligent transportation systems (ITS) clearly shows that utilization of IT systems have great importance to make cities "smarter". Thus, many cities around the world have started to apply to these systems to get smart city title, give good service to their citizens and save the humans and 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 of this project. In this study, used ISI systems and the transformation process are introduced in detail with all properties. Then, completed six ISIs performance evaluation analysis results are shared. Results show that ISIs have a great effect on the transformation cities to smarter cities and they have a positive effect on to reduce traffic chaos, control 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) projects in Turkey. It is conducted with the collaboration of Samsun Metropolitan Municipality (SMM) and ASELSAN for 2021 summer. During the project, transformation of total 72 fixed-time or non-signalized intersections to "Intelligent Signalized Intersections (ISI)", "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 e-Buses are started to use for public transportation is aimed carried out. Thus, SCTS project can be named as one of the biggest ITS project in Turkey.

3. INTELLIGENT SIGNALIZED INTERSECTIONS (ISI) APPLICATIONS

As a part of the implementation of the project, total 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 of all digital equipment have started in August 2021 and it is planning to finish in August 2023. Real site before-after transformation and construction im-ages for some ISIs are also given in Fig. 2.

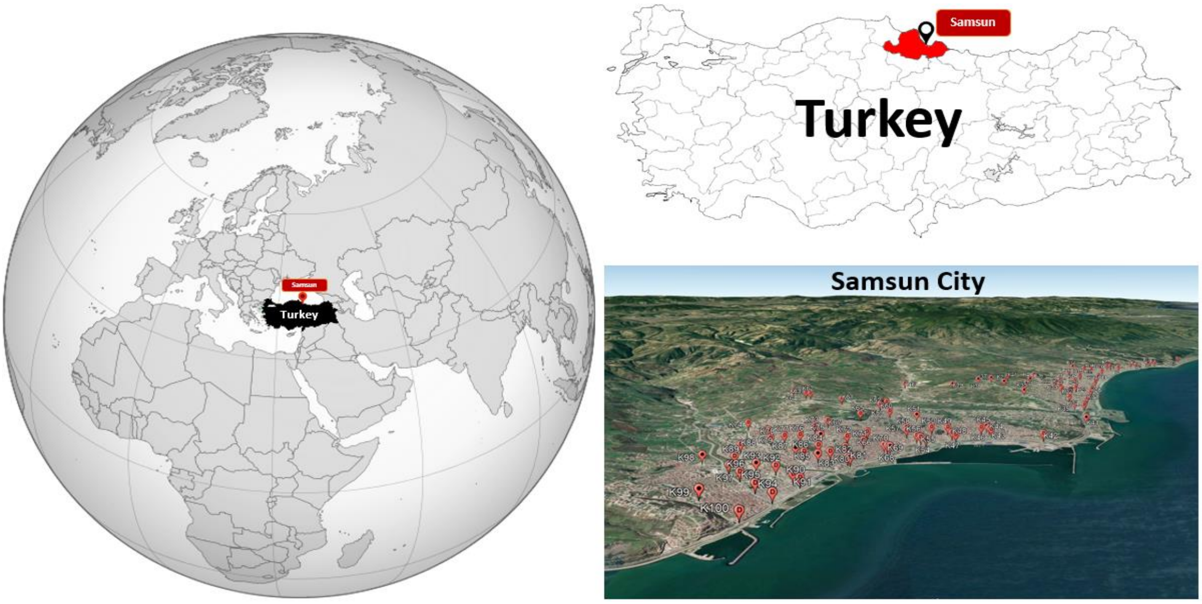


Fig. 1. Locations of 72 intelligent signalized intersections at urban roads in Samsun/Türkiye

(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 flowchart below (Fig. 3):

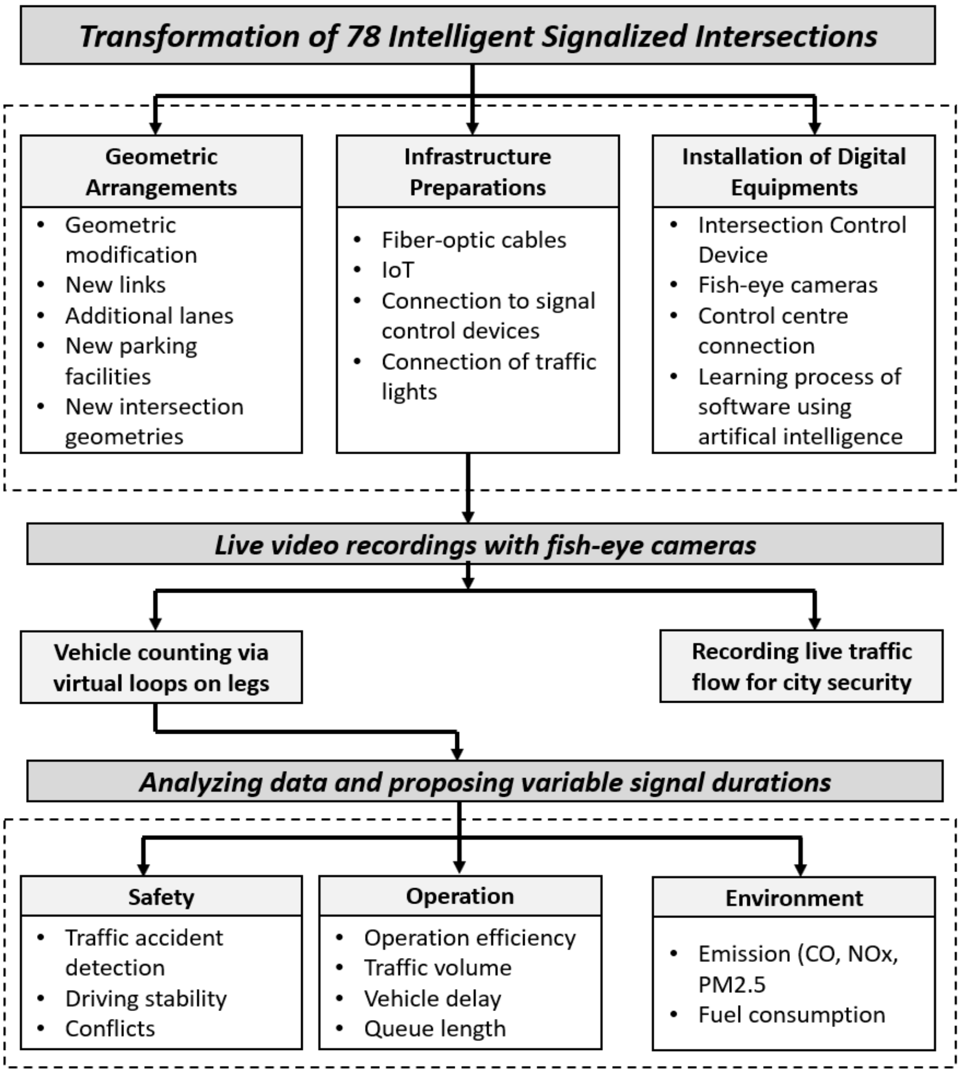


Fig. 3. Work packages and steps for the transformation of 78 intersections.

3.1. Definition of System Properties and Working Principles

Intelligent signalized intersection (ISI) systems with camera, is an instant traffic control and operation 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/exit directions of vehicles, vehicle classes and average speed etc. After data collection process, system pro-cess obtained data and it controls the signalized intersection instantly and regularly in real time. ISI system with traffic camera manages total cycle time of the signalized intersections by regulating green durations at intersection legs in an adaptive manner. It includes fully adaptive analysis method which helps to optimize the traffic control in real time. Thus, camera-based intelligent signalized system ensures high contributions to economy via reducing fuel consumption of vehicles; to human health by reducing gases emission; to driver psychology by reducing vehicle delays, total travel time in the traffic. ISI systems also include an intelligent traffic controller (ITC) de-vice, image processing device (IPD), fish-eye camera, camera pole (high 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, mathematical model and algorithms, artificial intelligence. This device also uses different traffic sensors and detectors which have ability to control from main traffic control room (Fig.4a).

b-) Image Processing Device (IPD). This device supplies many traffic related factors by using image processing technique through mathematical formulation and different algorithms. This device has an ability to detect and track moving and stopping vehicles. It also can count vehicles according to their types, determine 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 360-degree visual angle. Thus, they can complete intersection management in a 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 the real site applications, up to 18 meters poles for traffic cameras are used. Thus, they supply a good opportunity for the cameras to record real site videos for the analysis (Fig.4c).

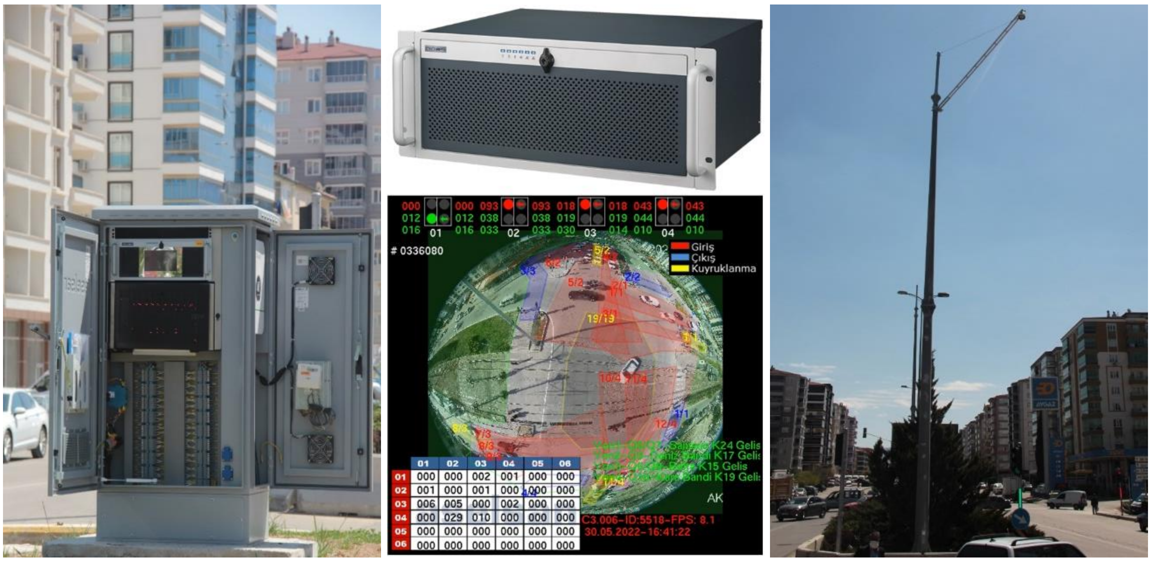
e-) Developed Software for Virtual Loop Editing. In the ISI, developed software helps to determine the limits of loop regions. Thus, vehicles can be detected and tracked via image processing method. This software has user friendly properties and it supplies draw, edit and apply options for virtual loops 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 to signalized intersections. Similarly, blue loops define exits from the signalized intersections. After completing loop design, developed software gives information regarding to real time traffic data n which are obtained by the designed loops. Developed user interface of the software supplies more than 50 different regions to be drawn and edited for the signalized intersections. 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.

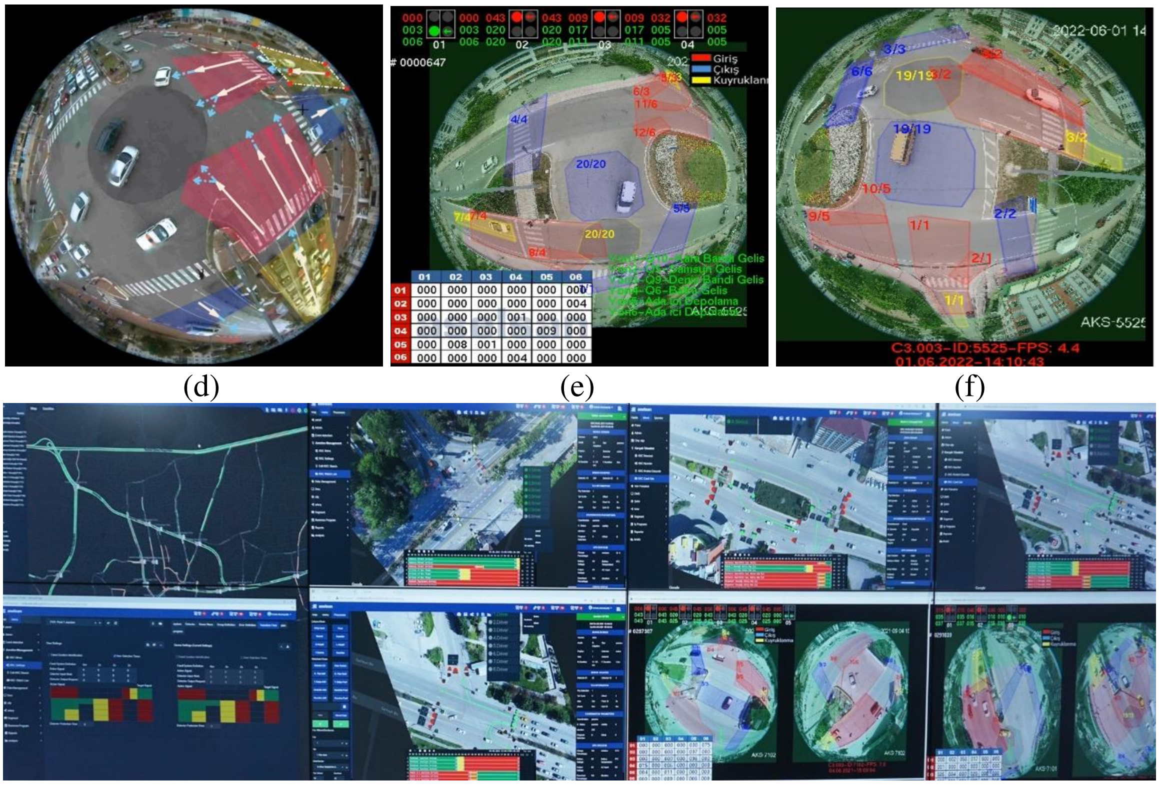
f.1-) Triggers on ISI Entering Lanes. In the developed software, the yellow regions are used to generate triggers before intersection entry. Software supplies to each line easy drawing options for yellow region, easily. Thus, operators can control duration of the lights for corresponding directions such as left turn, right turn and straight ahead, easily. On the other hand, system can calculate the percentage of occupancy for each lane of the intersection. Thus, it gives an 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 developed software, there are two regions inside the intersections defined as red and blue regions. These regions are used to obtain necessary statistical data during vehicle entering and exiting of vehicles to 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 working principle of the software, all vehicles are tracked from the red regions (entry) to inside (blue) regions. Hence, software can measure the vehicles numbers inside the intersection instantly and it also define their following routes. Thus, system can determine the congestion for the signalized intersection. Additionally, triggers can be generated before entry and exit lane 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, a reporting software is a very important step to understand the application results. This developed software supplies the results in various digital formats. As known, ISI system has vehicle tracking ability and all obtained analysis results can report 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).



(a) (b) (c)



(d) (e) (f)

(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 [18].

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 6 new ISIs data are obtained from the reporting software. The locations of examined ISIs are shown in Fig. 5.

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

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

(a) (b) (c)

(d) (e) (f)

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

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 were obtained by counting properties of the system software using image processing method. All vehicle numbers were determined by the counting of fish-eye cameras' real time recordings. During the counting process, vehi-cle types are classified in 4 groups as passenger car, minibus, bus/midibus and truck/lorry by the system software using image processing method.

4.2. Definition of System Properties and Working Principles

As can be seen from 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 at urban roads.

Tab. 2.

Vehicle and traffic flow statistics for 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 application of new intelligent intersection systems

Intersection No	Decrease in			
	Control Delays (sec.) (%)	Average Speeds (km/h) (%)	CO2 (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 the Table 3, changes for control delays, average vehicle speeds and emission values show differences at different ISIs. Traffic volume, driver characteristics and behaviors, vehicle and intersection types can show the most im-portant parameters on these results. It can be seen from the table that the highest decrease in control delays is observed at ISI-4 and least at ISI-1. Similar results are also obtained for average vehicles speeds in the same ISIs. These new intelligent sys-tems resulted in an average 16% decrease for control delays and %19 for average vehicle speeds. It can also be seen from the Table 3 that these new intersection management systems have an important role to reduce emissions at signalized intersections. These systems reduced average 1232 gr CO2 and 1542 gr PM10 daily. It can be concluded that ISIs have a great effect to reduce traffic chaos, control delays, vehicle speed and emissions.

5. CONCLUSIONS AND SUGGESTIONS

In the last decade, there has been a huge increase in applications of Intelligent Signalized Intersections (ISIs). Performance of new ISIs play a vital important role for safety and quality of travel on arterial networks in urban roads. On the other hand, collection of intersection performance data, such as vehicle control delay and queue length, is a time-consuming and labour-intensive task. In this paper, first used new ISIs and transformation of signalized intersections are introduced in detail. Then, performance evaluation of pilot new ISI applications at urban roads of Samsun City was made. Evaluation results showed that these new intelligent systems resulted in an average 16% decrease for control delays and %19 for 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 to reduce emissions which has a vital importance on climate change at signalized intersections. According to calculated results from the examined 6 new ISIs, transformation to intelligent intersections reduce average 1232 gr CO2 and 1542 gr PM10 daily. Thus, it can clearly reveal that ISIs have a great effect to reduce traffic chaos, control delays, vehicle speed and emissions as well as make cities “smarter”.

In this study, only completed 6 ISIs performance evaluation was made. Rest 72 ISIs transformation process still continue. 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 meet less complexity and emissions caused by the 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 British Council. The authors would like to thank British Council for this support. The authors also thank to Samsun Metropolitan Municipality, Ondokuz Mayıs University and Cardiff University for their partnerships and supports.

References

1. Yang, S., Bailey, E., Yang, Z., Ostrometzky, J., Zussman, G., Seskar, I., Kostic, Z. 2020. "*Cosmos smart intersection: Edge compute and communications for bird's eye object tracking*". In 2020 IEEE International Conference on Pervasive Computing and Communications Workshops (PerCom Workshops), 1-7, IEEE.
2. Karagiannis, G., Altintas, O., Ekici, E., Heijenk, G., Jarupan, B., Lin, K., Weil, T. 2011. "Vehicular networking: A survey and tutorial on requirements, architectures, challenges, standards and solutions". *IEEE Communications Surveys & Tutorials* 13(4): 584-616.
3. Olaya-Quiñones, J.D., Perafan-Villota, J.C. 2021. "*A smart algorithm for traffic lights intersections control in developing countries*". In: IEEE Colombian Conference on Applications of Computational Intelligence, 93-106, Springer, Cham.
4. Mu, H., Liu, L., Li, X. 2018. "Signal preemption control of emergency vehicles based on timed colored petri nets". *Discrete Dynamics in Nature and Society* (2018): 1-15.
5. Wang, X.B., Yin, K., Liu, H. 2018. "Vehicle actuated signal performance under general traffic at an isolated intersection". *Transportation Research Part C: Emerging Technologies* 95: 582-598.
6. Zheng, J., Wang, Y., Nihan, N.L., Hallenbeck, M.E. 2006. "Detecting cycle failures at signalized intersections using video image processing". *Computer-Aided Civil and Infrastructure Engineering* 21(6): 425-435.
7. Higashikubo, M., Hinenova, T., Takeuchi, K. 1998. "Traffic queue length measurement using an image processing sensor". *Sumitomo Electric Technical Review* 43: 64–68.
8. Fathy, M., Siyal, M.Y. 1995. "Real-time image processing approach to measure traffic queue parameters". *IEEE Proceedings: Vision, Image, and Signal Processing* 142(5): 297–303.
9. Yin, Z., Fan, Y., Liu, H., Ran, B. 2004. "*Using image sensors to measure real-time traffic flow parameters, Preprint CD-ROM*". 83rd Transportation Research Board Annual Meeting, January. Washington, DC, USA.
10. Gupte, S., Masoud, O., Martin, F.K.R., Papanikolopoulos, N.P. 2002. "Detection and classification of vehicles". *IEEE Transactions on Intelligent Transportation Systems* 3(1): 37–47.
11. Saito, M., Walker, J., Zundel, A. 2001. "Using image analysis to estimate average stopped delays per vehicle at signalized intersections". *Transportation Research Record: Journal of the Transportation Research Board* 1776: 106–113.

12. Saunier, N., Sayed, T. 2007. "Automated analysis of road safety with video data". *Transportation Research Record* 2019(1): 57-64.
13. Messelodi, S., Modena, C. M., Zanin, M. 2005. "A computer vision system for the detection and classification of vehicles at urban road intersections". *Pattern Analysis and Applications* 8(1): 17-31.
14. Rinner, B., Wolf, W. 2008. "An introduction to distributed smart cameras". *Proceedings of the IEEE*. 96(10): 1565-1575.
15. Shi, Y., Real, F.D. 2009. "*Smart cameras: Fundamentals and classification*", In Smart cameras, pp. 19-34, Springer, Boston, MA.
16. Hu, Z., Wang, C., Uchimura, K. 2007. "*3D vehicle extraction and tracking from multiple viewpoints for traffic monitoring by using probability fusion map*". In: 2007 IEEE Intelligent Transportation Systems Conference, 30-35, IEEE.
17. Subedi, S., Tang, H. 2018. "Development of a multiple-camera 3D vehicle tracking system for traffic data collection at intersections". *IET Intelligent Transport Systems* 13(4): 614-621.
18. URL-1, "Sinyalize Akıllı Kavşaklar", available at: https://www.mosas.com.tr/sinyalizasyon/solutions/cyclops/ last accessed 06/05/2022.

Received 24.01.2023; accepted in revised form XX.XX.XXXX