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Investigation of Pedestrian and Driver Behaviors at Push-Button Crosswalk on Main Arterials of Urban Roads: A Case of Samsun City, Türkiye

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Abstract

There are different types of crosswalks for pedestrians to cross the street and different methods of operation. Signalization can be used in the operation of at-grade and controlled crosswalk. In these crosswalks, signaling is activated by pedestrians pressing buttons placed on the crosswalks. In this type of crossing, pedestrians press the button to cross the road and the signaling system detects the request. Within a reasonable time, the system turns red for vehicles and green for pedestrians, allowing pedestrians to cross the street safely. However, these systems have some drawbacks. Various observation and data collection studies were carried out at the pilot pedestrian crossing on Atatürk Boulevard in Atakum district of Samsun province. In these studies, 227 pedestrians crossing the crosswalk and 791 vehicles stopped at red lights during the crossing of pedestrians were examined. As a result of the data obtained in line with pedestrian and driver behaviors, it is aimed to determine the operational problems in signalized crosswalk with pedestrian warning and to increase efficiency with the studies to be carried out.

Keywords: Crosswalk, push-button crosswalk, traffic accidents, pedestrian safety, traffic lights

1. Introduction

Unpredictable accidents that can occur at any time as a result of negligence and erroneous behavior can result in loss of life and property [1]. Traffic accidents are unpredictable events that occur on the highway, in which vehicles, drivers and pedestrians are involved separately or together, and which cause various negative effects as a result. [2].

Population growth and the parallel increase in the number of motorized vehicles increase traffic accidents [3]. Table 1 shows the number of vehicles registered to traffic, the total number of accidents and the number of deaths, injuries and material losses as a result of accidents between 2013 and 2022 [4]. As can be seen from the table, the number of vehicles registered to traffic increases regularly every year. The number of traffic accidents is expected to decrease with the developing vehicle technologies and intelligent transportation systems applications. However, when we look at the number of accidents, high numbers of accidents are noteworthy throughout all years. Only in 2020, there is a significant decrease in the total number of accidents. This situation is thought to be caused by the curfews imposed as a result of the Covid-19 pandemic. It is a fact that the pandemic process has caused large and irregular changes in traffic flow and the number of vehicles [5]. Although the number of deaths and injuries as a result of traffic accidents increased significantly between 2015-2017, it has been in a downward trend after 2017.

Table 1. Number of vehicles registered, accidents, persons killed and injured, 2013-2022 [4]

Year	Number of vehicles registered to traffic	Total number of accidents	Number of accidents involving death or injury	Number of accidents involving material loss only	Number of person killed	Number of person injured
2013	17.939.447	1.207.354	161.306	1.046.048	3.685	274.829
2014	18.828.721	1.199.010	168.512	1.030.498	3.524	285.059
2015	19.994.472	1.313.359	183.011	1.130.348	7.530	304.421
2016	21.090.424	1.182.491	185.128	997.363	7.300	303.812
2017	22.218.945	1.202.716	182.669	1.020.047	7.427	300.383
2018	22.865.921	1.229.364	186.532	1.042.832	6.675	307.071
2019	23.156.975	1.168.144	174.896	993.248	5.473	283.234
2020	24.144.857	983.808	150.275	833.533	4.866	226.266
2021	25.249.119	1.186.353	187.963	998.390	5.362	274.615
2022	26.482.847	1.232.957	197.261	1.035.696	5.229	288.696
Total	221.971.728	11.905.556	1.777.553	10.128.003	53.547	2.848.386

Table 2 shows the distribution of victims in fatal and injury traffic accidents in 2022 in terms of drivers, passengers and pedestrians. Pedestrians account for 23.2% of fatalities and 12.8% of injuries in traffic accidents [4]. Pedestrian-oriented studies are also needed to eliminate the negative consequences of traffic accidents. The vulnerability of pedestrians to collisions makes the consequences of accidents more serious [6]. The risk of death and injury increases in accidents caused by vehicles hitting pedestrians.

Table 2. Number of victims of traffic accidents involving death or injury, 2022 [4]

Victims		
Driver	Number of persons killed	2.349
	Number of persons injured	141.795
Passenger	Number of persons killed	1.662
	Number of persons injured	109.790
Pedestrian	Number of persons killed	1.218
	Number of persons injured	37.111
Total	Number of persons killed	5.229
	Number of persons injured	288.696

Table 3 shows that 7.99% of the traffic accidents in 2022 occurred at crosswalk and 0.39% at school crossings [7]. Although the accidents involving pedestrians are not only at crosswalks and the proportion of accidents occurring at pedestrian and school crossings in total accidents is quite low, the fact that pedestrians account for 23.2% of the deaths and 12.8% of the injuries in traffic accidents given in Table 2 is a situation that requires attention. It can be seen that accidents are concentrated in areas where the interaction between pedestrians and vehicles increases [8].

As can be seen from the table, fatal and injury accidents occur at a much higher rate in urban areas than in rural areas. However, the potential for vehicles to travel at higher speeds in rural areas may cause accidents to be more fatal.

Table 3. Traffic accident information with fatal and injury according to road type, 2022 [7]

	Residential area		Rural area		Total	
Crossovers	Number	(%)	Number	(%)	Number	(%)
Crosswalk	15.120	9,28	642	1,85	15.762	7,99
School crossings	742	0,46	30	0,09	772	0,39
Controlled rail crossing	302	0,19	16	0,05	318	0,016
Uncontrolled railway crossing	57	0,04	15	0,04	72	0,04
No crossings	146.446	90,03	33.891	97,97	180.337	91,42
Total	162.667	100	34.594	100	197.261	100

Accidents are unforeseen incidents that occur as a result of erroneous behavior. Accidents can occur for many reasons. When the causes of accidents (Table 4) are analyzed, it is seen that drivers have the largest share. Almost 9 out of every 10 accidents are caused by driver-related reasons. Unfortunately, driver errors can cause irreversible consequences. In addition to driver errors, although road and vehicle defects cause accidents, the other prominent factor is pedestrian errors. Almost 1 out of every 10 traffic accidents is caused by pedestrian errors [4] Therefore, in order to effectively combat accidents, driver and pedestrian behaviors should be well examined and the factors that trigger errors should be identified. Thus, the risk of accidents can be reduced by eliminating the factors that cause accidents and making necessary improvements.

Table 4. Number of faults causing traffic accidents involving death or injury, 2013-2022 [4]

	Driver faults		Passenger Faults		Pedestrian faults		Road faults		Vehichle faults	
Year	Number	(%)	Number	(%)	Number	(%)	Number	(%)	Number	(%)
2013	162.327	88,7	774	0,4	16.458	9,0	1.913	1,0	1.558	0,9
2014	171.236	88,6	901	0,5	18.115	9,4	1.841	1,0	1.122	0,6
2015	187.980	89,3	915	0,4	18.522	8,8	1.916	0,9	1.165	0,6
2016	190.954	89,6	869	0,4	18.612	8,7	1.717	0,8	997	0,5
2017	191.717	89,9	782	0,4	18.095	8,5	1.619	0,7	1.112	0,5
2018	194.928	89,5	1.916	0,9	18.394	8,4	1.300	0,6	1.360	0,6
2019	180.042	88,0	2.572	1,3	16.726	8,2	1.045	0,5	4.153	2,0
2020	157.128	88,3	2.577	1,4	12.520	7,0	897	0,5	4.745	2,7
2021	195.382	87,1	3.941	1,8	18.398	8,2	936	0,4	5.761	2,6
2022	204.233	86,8	2.753	1,2	22.234	9,5	902	0,4	5.054	2,1

Although there are many factors in the occurrence of accidents, as seen in Table 4, pedestrian-related errors are an important cause. This situation reveals the necessity of pedestrian-oriented studies. Pedestrian behaviors effective in the occurrence of accidents were examined. Acting in a way that endangers vehicles on the roads has the highest rate of error in accidents caused by pedestrians with 29.6%.

Pedestrians trying to cross the road outside the designated areas where there are no crosswalk or intersections is also the leading cause of accidents with a rate of 27.3%. Pedestrians frequently cross the road where there are no crossings and without following the rules. In order to create a safer traffic infrastructure, it is important to manage crosswalk in a more planned manner and to raise awareness among pedestrians and drivers. Another important type of error is violating traffic lights and signals, such as crossing into the path of vehicles and violating traffic rules when crossing the road (Table 5) [4].

Table 5. Faults causing road traffic accidents involving death or injury, 2022 [4]

Pedestrian faults	Number	(%)
Violating crossing rules where crosswalk and junctions not exist	6.079	27,3
Violating traffic lights ans signals	2.755	12,4
Acting behaviours on vehicle roads that endanger traffic vehicles	6.571	29,6
Violating traffic rules while crossing roads	209	0,9
Entering the vehicle road	474	2,1
Not walking on the left side of the vehicle road	245	1,1
Not taking accident preventing cautions where night and day vision is unclear	592	2,7
Other pedestrian faults	5.309	23,9
Total	22234	100

There are different types and methods of operation of crosswalks (Fig. 1). Crosswalks are divided into two as At-grade crossing and Grade-separated crossing, depending on the plane on which they are built. Grade-seperated crossings are underpass and overpass. At-grade crossings are divided into controlled and uncontrolled [9].

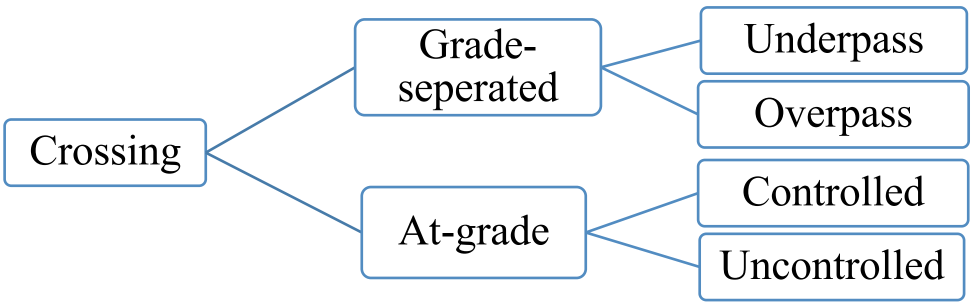

Fig. 1. Crossing operating modes [9]

Controlled crosswalk can be implemented with police supervision or by using signalization systems. It is not sustainable to manage all crosswalk with police supervision. Signalization is widely used in the operation of level and controlled crosswalks. Unlike crosswalks at intersections, supervised crosswalks along road axes are usually pedestrian-activated. When the pedestrian arrives at the crossing to cross the road, he/she activates the system by pressing the button on the signaling pole (Fig. 2). In line with the pedestrian's right of way request, the signaling system turns on a red light for vehicles and a green light for pedestrians within a certain period of time. Thus, pedestrians can safely cross the pedestrian crossing when the vehicles stop within the allotted time.

a) [10] b) [11] c) [12]

Fig. 2. Crosswalk button examples

However, there are some problems in the operation of pedestrian push-button signalization systems at crosswalks. First of all, pedestrians who do not know the working logic of the system try to cross the road when they find suitable intervals between vehicles without using the signalization system, which creates accident risks. Another issue is that pedestrians cross the street without waiting for the green light after pressing the button. In this case, while the pedestrian is completing the crossing or later, if the light turns green for pedestrians, the red light also turns red for vehicles, and vehicles continue to stop in vain after the pedestrian has finished crossing. In this scenario, vehicles will consume unnecessary fuel and emit unnecessary exhaust emissions, resulting in economic losses as well as environmental damage. In addition, the delay time of vehicles increases as a result of unnecessary stopping of vehicles.

Within the scope of the study, the failures occurring at pedestrian signalized crosswalks with pedestrian warning systems will be examined. As a result of the data obtained in line with pedestrian and driver behaviors, it is aimed to determine the operational problems in signalized crosswalks with pedestrian warning and to increase efficiency with the studies to be carried out. With a more efficient pedestrian crossing, it is aimed to increase pedestrian safety and reduce fuel consumption and exhaust emissions by eliminating unnecessary waiting for vehicles. In this direction, a pilot pedestrian crossing was determined and data on pedestrians and drivers were obtained through observations. The results show that there is potential for academic studies and field applications related to crosswalks.

1.1. Background

Crosswalks are areas arranged for the common use of vehicles and pedestrians with horizontal and vertical markings or traffic lights [13]. However, in developing cities, the vehicle-oriented service concept leaves pedestrians in the background [14]. The intersection of pedestrian and vehicle traffic brings potential risks. Based on this point, there are crosswalks and overpasses that aim to reduce accidents by separating pedestrian traffic from vehicle traffic [15].

Although pedestrian safety is a very important problem in developing countries such as Türkiye, it is generally not given importance [16]. Accidents may also occur due to inadequate or incorrect physical conditions of crosswalks [17-19]. Accidents can be prevented by establishing the right traffic management infrastructure [20].

In crosswalks, the absence or improper planning of signals for crosswalks also triggers accidents [21-23]. Similarly, the failure of pedestrians or drivers to comply with the existing signal planning or to use it correctly can also cause disruptions. Failure to fully know or recognize the rules also leads to violations [24].

In order to prevent traffic accidents at crosswalks and the negative consequences of these accidents, it is very important to correctly identify the factors that cause accidents. [25]. There are many studies examining pedestrian behavior at crosswalks, the factors determining crossing behavior and the effects of traffic conditions on behavior [26-29]. In these studies, pedestrian non-compliance with the rules is the leading cause of accidents. Pedestrian behavior may vary depending on many parameters. These differences may vary from country to country [30], or even in different cities within the same country [31,32]. For this reason, as in many traffic engineering problems, regional studies can be conducted on pedestrian-oriented issues and regional solutions can be developed. In this way, the traffic culture of that society can be better understood and the efficiency of the solutions developed will increase.

Failure of pedestrians to obey traffic lights eliminates the concept of controlled crosswalks. At this point, the reasons why pedestrians do not obey the rules should be examined well. Thus, changes can be made and measures can be taken to ensure that pedestrians obey the rules in line with the reasons determined. When the reasons for pedestrians not obeying traffic lights in the literature are examined, the behavior of pedestrians being in a hurry comes first. The increase in the waiting time as a result of the long red light duration or the thought that pedestrians can cross safely without waiting due to low traffic volume increases light violations [33-35].

A smooth operational infrastructure at crosswalks can only be achieved if drivers, but especially pedestrians, fully comply with the rules. In order for pedestrians to fully comply with the rules, pedestrian behaviors, expectations and dissatisfaction should be well examined and necessary changes should be made accordingly. Pedestrian safety and crosswalks will continue to be an interesting area of research for researchers.

2. Data collection and evaluation

2.1. Determining the region and obtaining data

In order to investigate driver and pedestrian behaviors at pedestrian crosswalks with pedestrian push-button control, a pedestrian crosswalk with pedestrian push-button located on Atatürk Boulevard (D010 - Samsun Sinop road) in Körfez neighborhood of Atakum district of Samsun province was examined (Fig. 3). In determining this pedestrian crossing, observation of heavy pedestrian and vehicle traffic was effective due to the density of commercial enterprises around the region, the location on the crossing route to the beach, and the schools and Ondokuz Mayıs University campus around it.

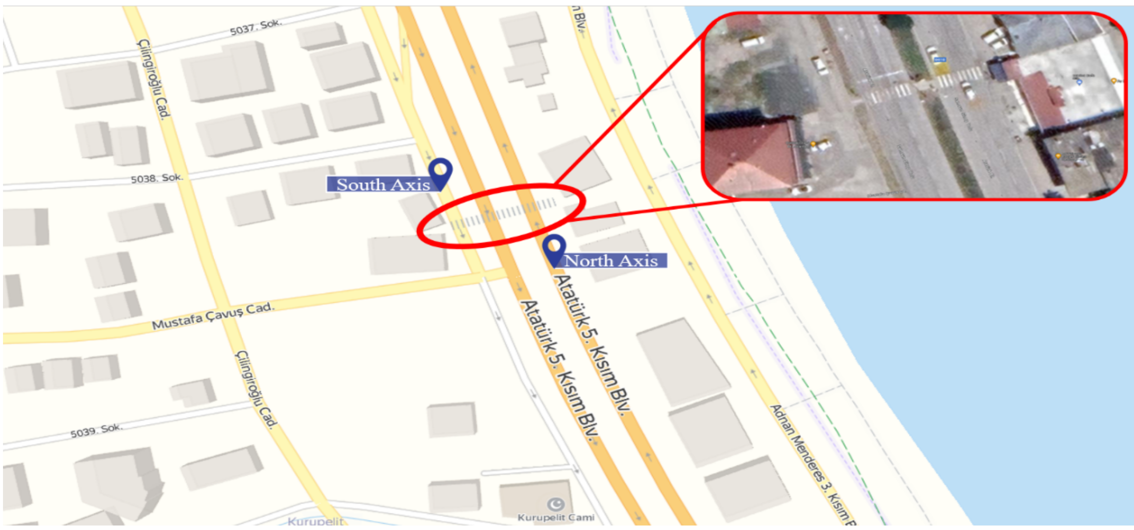

Fig. 3. Pilot area location [36-37]

In a study conducted to determine the traffic risk index of provinces in Türkiye, Samsun was found to be 65th risky in Türkiye [38]. Although this suggests that Samsun is one of the least risky cities in terms of traffic, the intense pedestrian and vehicle mobility, especially around Ondokuz Mayıs University and on the coastal line, brings various risks.

According to TÜİK statistics on the number of traffic accidents, deaths and injuries by provinces (2022), a total of 19,540 traffic accidents occurred in Samsun in 2022. 3,626 traffic accidents resulted in death or injury and 110 people died and 5,399 people were injured in these accidents [4]. In terms of the total number of traffic accidents, deaths and injuries, it is seen that Samsun province ranks quite high in the list. The ratio of people killed and injured per accident is also higher in Samsun province compared to Türkiye average.

In the section where the pilot pedestrian crossing is located, both directions have 3 lanes each and the directions are named as north and south axes (Fig. 4). The distance required for pedestrians to cross the road is approximately 23 meters. The crossing speed of pedestrians at crosswalks varies according to age and gender [39]. Although there are many studies on pedestrian crossing speeds in the literature [40], it would be a better approach to take into account the current studies conducted in Türkiye, considering that pedestrian behavior varies from country to country. The average crossing speed of pedestrians at crosswalks is assumed to be 0.9 m/sec.

Fig. 4. Pilot area axes [37]

The pedestrian crossing in the pilot area is a pedestrian crossing with pedestrian push-button signalization control. At the starting point of the crosswalk in both directions and at the traffic island, there are pedestrian buttons (marked) as shown in Fig. 5. Pedestrian buttons are located at the starting point in both directions and at the traffic island. When pedestrians press the button to cross the street, the system is activated and vehicles are stopped with a red light while pedestrians are signalized with a green light to cross the street safely.

Fig. 5. Pilot area and crosswalk button

In order to examine pedestrian and vehicle behaviors at the pedestrian crossing with pedestrian warning control in the designated pilot area, video recordings were taken during peak hours (between 3.30 pm and 6.00 pm) when vehicle and pedestrian traffic is intense for 10 days. Pedestrian and vehicle behaviors from video recordings were manually examined by the researchers, the times were determined with a stopwatch and the images were converted into numerical data.

2.2. Examining pedestrian behavior

Within the scope of the study, the crossing movements of 227 pedestrians using the pilot pedestrian crossing were analyzed. Pedestrian crossing movements fluctuate during the day, such as fluctuations in traffic flow. The observations revealed that the number of pedestrian crossing usage increases during the rush hours of work and school (16.00-18.00). As a result of the observations made and the examination of the video recordings obtained, it was determined that 62 pedestrians out of 227 pedestrians using the crosswalk crossed the road without using the buttons placed to give pedestrians the right of way. While 48 of 62 pedestrians waited for the traffic flow to decrease without pressing the button, 14 pedestrians who did not press the button crossed the road directly without waiting. 165 pedestrians pressed the button and waited for the right of way to be granted to them (Fig. 6).

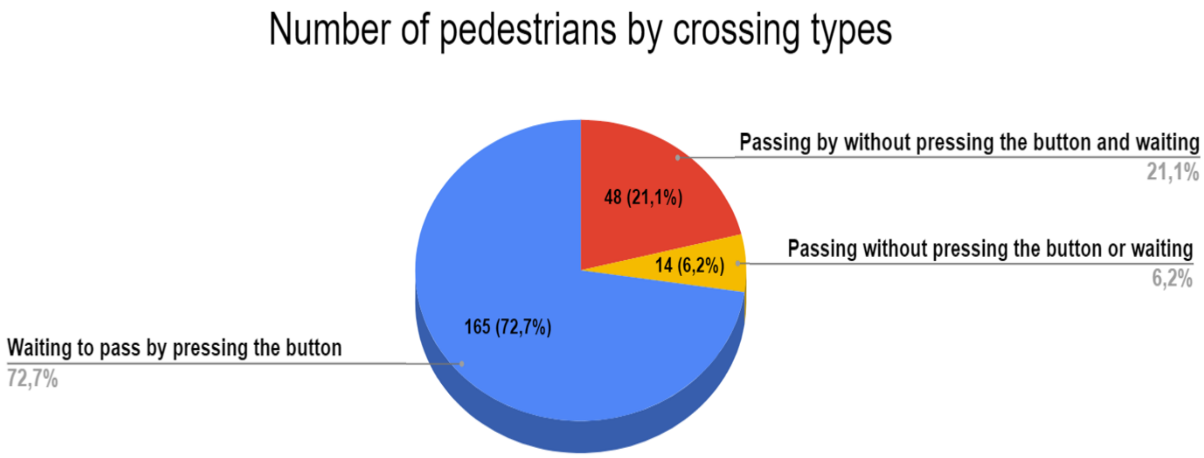

Fig. 6. Number of pedestrians by crossing types

In line with the data obtained, it can be said that the majority of pedestrians (72.7%) using the pedestrian crossing use the buttons. However, a significant portion (27.3%) do not use the buttons. In addition, there is a group of 21.1% who do not use the button even though they are waiting, which means that they do not have any knowledge about the working logic of the system. Although a large proportion of pedestrians cross safely by using the pushbutton, it is necessary to increase the rate of pushbutton use and to give pedestrians this habit. However, when the traffic density is not high, pedestrians may want to activate the system and cross the street at a convenient time without stopping the vehicles. In addition to lack of knowledge, this type of behavior can also be observed in pedestrians who do not use the button. Whether pedestrians do not want to use it or do not know the system cannot be fully determined by observations.

There were 165 pedestrians who crossed the street using the pushbutton at crosswalks, and the crossing movement was carried out in groups in a total of 67 times. Crossing movements were categorized and named according to the direction of crossing (Fig. 7).

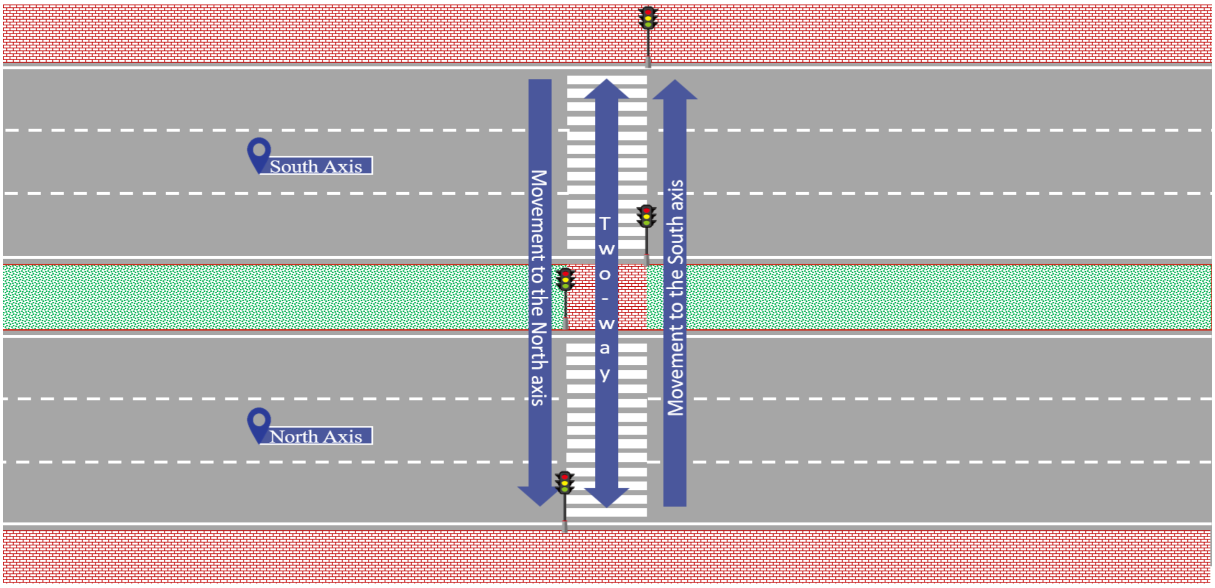

Fig. 7. Movement directions

Out of 67 different crossing movements, pedestrians crossed to the north axis 31 times and to the south axis 25 times. 11 crossings were observed in opposite directions (Fig. 8). It can be said that the lack of equal distribution according to directions is due to the surrounding places such as workplaces and beaches, as well as the traffic flow that changes directionally.

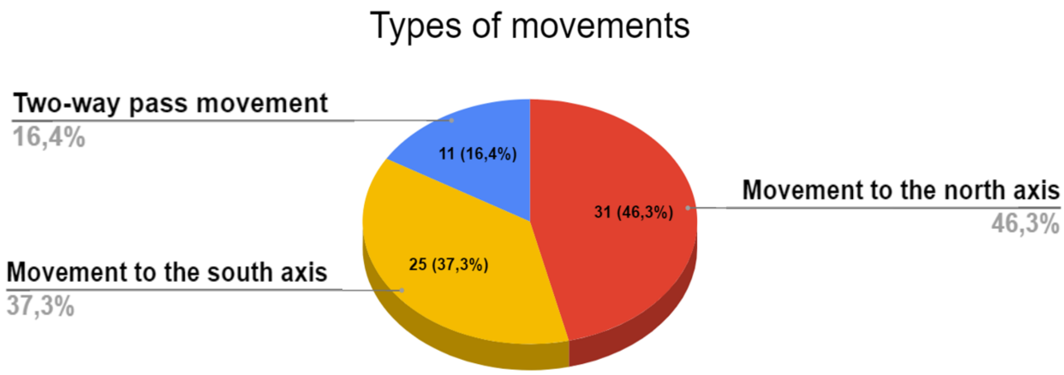

Fig. 8. Types of movements

It was also found that 83.6% of the crossings were one-way crossings. When pedestrians press the button in either direction, the red light for both axes is illuminated for vehicles. In other words, when pedestrians press the button on the south axis and cross to the north axis, and when pedestrians press the button on the north axis and cross to the south axis, vehicles turn red on both axes when pedestrians press the button. However, pedestrians are crossing gradually and it can be said that pedestrians are moving on only one axis at first. Vehicles on the other axis pause unnecessarily. For this reason, different or staggered circuit schemes can be applied on the axles if necessary.

Pedestrians' button pressing positions were also analyzed. Pedestrians pressed the button at the north or south starting point 51 times, while 16 times they crossed the first section without pressing the button and pressed the button at the traffic island. Similarly, when pushing the button at the traffic island, pedestrians benefit from the pause of vehicles to cross only one direction. However, the other direction unnecessarily waits at the red light. Unnecessary hesitation increases fuel consumption, exhaust emissions and delays. Unnecessary waiting can also create tension among drivers and trigger red light running.

In addition to drivers, the system also has drawbacks for pedestrians. At crosswalks with pedestrian warning signalization systems, after pedestrians press the button, a red light for vehicles and a green light for pedestrians turn on after a certain period of time and pedestrians have the opportunity to cross safely during this period. However, in 11 out of 67 observations, it was observed that pedestrians crossed the street before the green light turned on after pressing the button. Observations have shown that the green light for pedestrians turns on very shortly after the button is pressed. Pedestrians wanting to cross the street without waiting creates possible accident risks. In addition, there is a possibility that pedestrians may cross without using the button after waiting for a few seconds, while pressing the button unnecessarily stops the vehicles after they have crossed. These situations prevent the system from working effectively. In this direction, the system can be operated more efficiently with simple solutions such as pedestrians holding the button or waiting on an area on the ground where sensors are placed.

During the examination of the crossing movements at the pedestrian crossing, it was determined that the pedestrian push-buttons were used 67 times. When all rounds were analyzed, the average of 2 pedestrians crossed for each round, while the standard deviation value was found to be 1.5. For the 67 rounds of crossing movements, the parameters of the crossing movements such as the position of the button press, the position of the pedestrians when the light turns green for pedestrians, the number of pedestrians crossing in that round, the direction of the crossing movement, the waiting time for pedestrians and the segment in which the pedestrians crossed are analyzed and presented in Table 6.

Table 6. Obtained pedestrian movement data

Movement Number	Button Pressed Position	Position of the Pedestrian When It Turns Green	Number Of Pedestrians Waitıng	Pedestrian Movement Direction	Waiting Time Of The Longest Waiting Pedestrian (sec.)	Average waiting time of pedestrians (sec.)	Did the pedestrian cross the green side? / *
1	Traffic Island	Traffic Island	2	North	11	11	Yes
2	Sidewalk	Road	3	North	4	4	No / 4
3	Sidewalk	Sidewalk	3	Two-way	10	8	Yes
4	Sidewalk	Sidewalk	3	South	8	8	Yes
5	Traffic Island	Traffic Island	2	North	21	21	Yes
6	Sidewalk	Sidewalk	2	South	10	10	Yes
7	Sidewalk	Sidewalk	2	South	9	9	Yes
8	Sidewalk	Sidewalk	1	South	9	9	Yes
9	Traffic Island	Traffic Island	1	North	12	12	Yes
10	Traffic Island	Traffic Island	1	North	8	8	Yes
11	Sidewalk	Road	1	South	3	3	No / 5
12	Sidewalk	Sidewalk	4	North	10	10	Yes
13	Sidewalk	Sidewalk	3	North	10	10	Yes
14	Sidewalk	Sidewalk	3	South	15	15	Yes
15	Sidewalk	Sidewalk	1	North	13	13	Yes
16	Sidewalk	Sidewalk	1	South	10	10	Yes
17	Traffic Island	Traffic Island	3	North	37	27,33	Yes
18	Sidewalk	Sidewalk	1	South	13	13	Yes
19	Sidewalk	Sidewalk	1	South	5	5	No / 5
20	Traffic Island	Traffic Island	1	North	9	9	Yes
21	Sidewalk	Sidewalk	5	Two-way	13	8,5	No / 2

22	Sidewalk	Sidewalk	2	South	8	8	Yes
23	Traffic Island	Road	3	North	5	5	No / 3
24	Traffic Island	Traffic Island	6	Two-way	20	15,33	Yes
25	Traffic Island	Traffic Island	3	North	16	16	Yes
26	Sidewalk	Road	2	Two-way	5	5	No / 4
27	Sidewalk	Sidewalk	1	South	19	19	Yes
28	Traffic Island	Traffic Island	5	North	20	20	Yes
29	Traffic Island	Road	4	North	11	11	No / 3
30	Sidewalk	Sidewalk	2	Two-way	10	10	Yes
31	Sidewalk	Sidewalk	2	North	8	8	Yes
32	Sidewalk	Sidewalk	1	North	9	9	Yes
33	Sidewalk	Sidewalk	6	North	26	16,6	Yes
34	Sidewalk	Sidewalk	7	North	25	16,67	Yes
35	Sidewalk	Sidewalk	2	North	8	8	Yes
36	Sidewalk	Sidewalk	1	North	9	9	Yes
37	Sidewalk	Sidewalk	3	Two-way	9	9	Yes
38	Traffic Island	Traffic Island	1	North	8	8	Yes
39	Traffic Island	Traffic Island	1	North	6	6	No / 3
40	Sidewalk	Sidewalk	1	South	8	8	Yes
41	Sidewalk	Sidewalk	1	North	7	7	Yes
42	Traffic Island	Road	2	North	3	3	No / 5
43	Sidewalk	Sidewalk	1	South	8	8	Yes
44	Traffic Island	Road	1	South	5	5	No / 3
45	Sidewalk	Sidewalk	3	North	8	8	Yes
46	Sidewalk	Sidewalk	4	Two-way	18	18	Yes
47	Sidewalk	Sidewalk	2	North	10	10	Yes
48	Sidewalk	Sidewalk	3	South	17	17	Yes
49	Sidewalk	Sidewalk	2	South	9	9	Yes
50	Sidewalk	Sidewalk	1	South	8	8	Yes
51	Sidewalk	Sidewalk	3	North	8	8	Yes
52	Sidewalk	Sidewalk	2	Two-way	8	8	Yes
53	Sidewalk	Sidewalk	5	North	11	11	Yes
54	Sidewalk	Sidewalk	2	South	16	16	Yes
55	Sidewalk	Sidewalk	2	South	12	12	Yes
56	Sidewalk	Sidewalk	5	North	8	8	Yes
57	Sidewalk	Sidewalk	1	South	8	8	Yes
58	Sidewalk	Sidewalk	2	South	8	8	Yes
59	Sidewalk	Sidewalk	5	Two-way	9	9	Yes
60	Sidewalk	Sidewalk	2	South	8	8	Yes
61	Sidewalk	Sidewalk	2	Two-way	8	8	Yes
62	Sidewalk	Road	5	Two-way	10	8,33	No / 3
63	Sidewalk	Sidewalk	4	South	8	8	Yes
64	Traffic Island	Traffic Island	1	North	9	9	Yes
65	Sidewalk	Sidewalk	3	North	51	24,33	Yes
66	Sidewalk	Sidewalk	1	South	8	8	Yes
67	Sidewalk	Sidewalk	3	South	8	8	Yes

* If the pedestrian crossed on red, how many seconds after it turned green?

During the 67 rounds in which the pedestrians activated the signalization system, the time they waited for the right of way to be granted to them was obtained. The average waiting time of pedestrians is 10.4 seconds for all rounds with a standard deviation of 4.78 seconds. Fig. 9 shows that the waiting times are much lower or higher than the average.

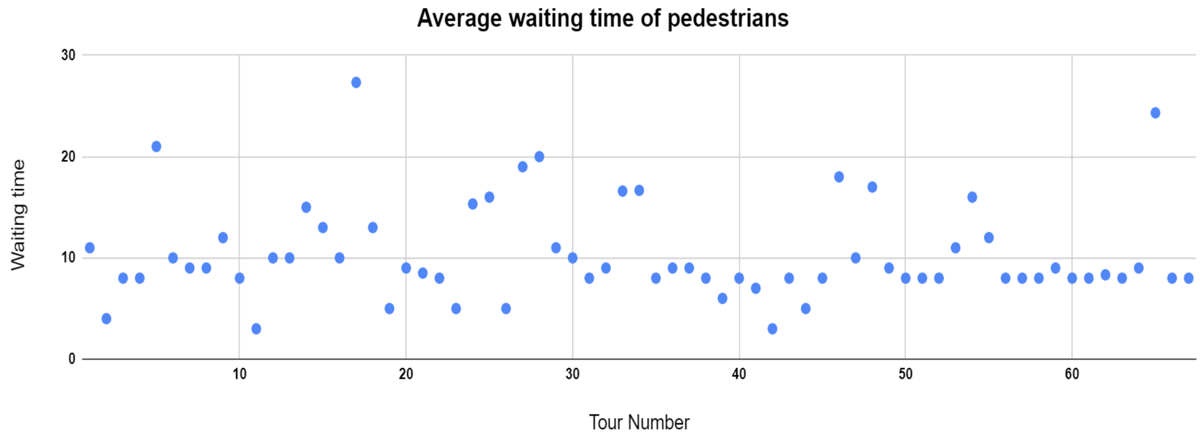

Fig. 9. Average waiting time of pedestrians

The longest waiting time for pedestrians waiting for a green light was also analyzed. The average waiting time for all rounds is 11.4 seconds with a standard deviation of 7.55 seconds. It can be seen from the data that although the waiting times are quite short, some rounds have high waiting times. More efficient and safer solutions for pedestrians should be developed with a more systematic pedestrian push-button signalization system.

According to the data obtained, 46.3% of the crossing movements in 67 different rounds were made on the north axis and 37.3% on the south axis. In 16.4% of the crossing movements, a two-way crossing was realized. In addition, pedestrians generally pressed buttons on the sidewalks at points that can be considered as starting points for crossing (76.1%). However, some pedestrians (23.9%) did not use the pushbutton on the first axis when the traffic flow was calm for crossing the street, but used the pushbutton when they reached the traffic island due to the heavy traffic flow on the other axis (Fig. 10).

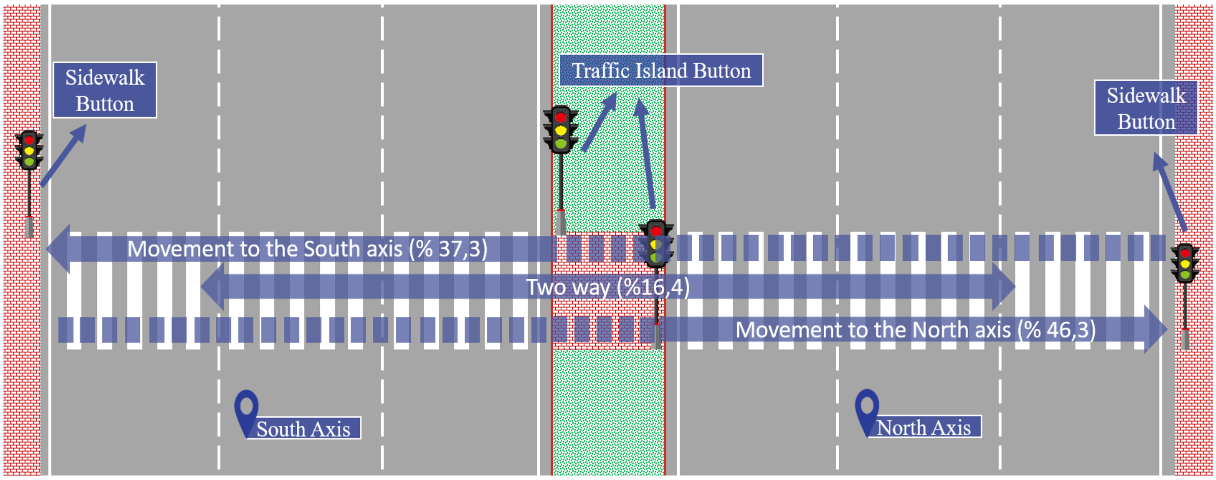

Fig. 10. Movement distribution according to movement directions

It has been observed that pedestrians tend to cross before the light turns green if there is a dilution in the traffic flow after pressing the button and there is an opportunity to cross. The locations of pedestrians who pressed the button when the light turned red for vehicles and green for pedestrians were also analyzed within the scope of the study. 11.9% of the pedestrians did not wait for the green light to turn on and turned green when they were on the road platform. When the light turned green, 70.2% of pedestrians waited on the sidewalk and 12% waited on the traffic island.

2.3. Examining driver behavior

At crosswalks with pedestrian push-button signaling systems, a red light is turned on for vehicles at the same time as a green light is turned on for pedestrians to give pedestrians the right of way. Thus, vehicles are kept waiting for pedestrians to cross safely.

Within the scope of the research, a total of 791 vehicles were stopped due to red lights during the 67 rounds in which the system was activated. The information about the vehicles stopped at red lights (how many vehicles stopped, the waiting time of the first stopped vehicle, average waiting time) is given in Table 7.

Table 7. Obtained vehicle data stopping at the pedestrian crossing

Tour Number	Number of Vehicles Waiting at Red Light	Waiting Time for the First Vehicle to Stop (sec.)	Average Waiting Time of Vehicles for South Axis (sec.)	Average Waiting Time of Vehicles for North Axis (sec.)
1	10	25	14,5	15,00
2	4	24	11	20
3	7	25	23,67	16,25
4	10	23	7,5	15,50
5	8	23	10,5	14,75
6	9	25	20,75	20,00
7	9	24	13	18,67
8	6	25	12,25	19
9	11	13	11,88	10
10	3	18	18	13,5
11	8	25	13,6	18
12	9	23	14,57	18
13	7	24	15,8	21,5
14	8	25	23	15,29
15	22	25	15,87	16,33
16	12	25	9,57	13
17	16	26	16	15,75
18	15	25	19,69	9,5
19	18	25	17,5	16,5
20	11	24	9	15,33
21	7	25	10	18,6
22	4	18	6	15
23	4	21	13	14,67
24	12	25	19,33	19,67
25	16	26	16	15,75

26	4	22	12	16,67
27	20	24	13,58	21
28	7	24	3,67	15,75
29	23	25	14,17	0
30	18	25	17,00	22
31	24	26	16,45	18,75
32	4	24	14	24
33	16	25	7,57	17
34	13	24	18,33	7,25
35	18	26	18,56	14,5
36	21	26	17,39	11
37	5	25	9,67	22,5
38	23	25	16,37	19,5
39	18	21	13,31	8,5
40	10	26	18,29	10
41	10	25	9,40	19,6
42	21	25	19,07	0
43	18	25	15,93	23,3
44	5	21	0	15,4
45	4	18	0	11,5
46	7	27	21	14,33
47	14	27	7,5	18,33
48	8	22	12,17	14,5
49	4	22	22	17,67
50	3	19	11,5	19
51	0	0	0	0
52	14	23	15,69	11
53	12	26	7,67	20,17
54	8	15	12,5	13,5
55	9	23	12	18,8
56	17	26	14,62	11
57	21	25	17	15,17
58	17	24	16,08	18,8
59	16	22	14,33	12,5
60	19	7	14,67	3,75
61	21	8	15,33	13,6
62	19	25	18,53	10,5
63	5	17	16	11,67
64	20	25	18	19
65	15	23	13,64	22
66	5	24	0	15,8
67	9	23	5,67	16,83
Mean ($\bar{x}$)	12	23	13,4	15,2
SD (σ)	6,29	4,8	5,4	5,1

SD (σ) : Standart deviation

As a result of the observations, average waiting time of vehicles for south axis was 13.4 seconds (SD=5.4) and average waiting time of vehicles for north axis was 15.2 seconds (SD=5.1). It was also found that an average of 12 vehicles stopped for each round and the first stopped vehicle waited at the red light for an average of 23 seconds. No vehicle waited at the red light for 3 rounds for South axis and 2 rounds for North axis. As a result of the observation, it can be said that the volume value for the south axis is higher than the north axis. It is thought that this is due to the fact that there is usually a movement of leaving work and returning to residential areas during the observation periods. The number of vehicles waiting at red lights during the rounds is given in Fig. 11.

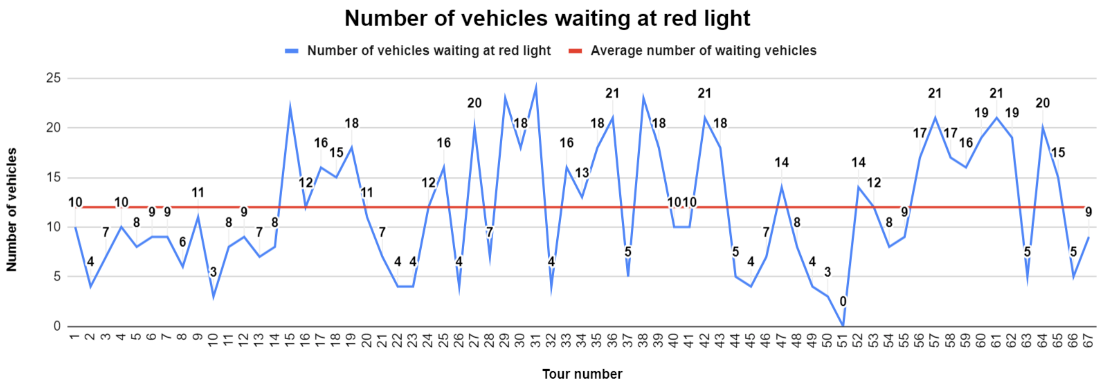

Fig. 11. Number of vehicles waiting at red light

In the observations made within the scope of the study, it was determined that an average of 12 vehicles paused at crosswalks as a result of the signalization system during all rounds. When the graph is analyzed, it is determined that 6 or less vehicles stopped at the lights in 15 rounds. This shows that on the road with 2 directions and 3 lanes, assuming that the vehicles are equally distributed directionally, an average queue of 1 vehicle is formed in each lane. In the 40 laps, 12 or less vehicles stopped at the lights. Similarly, on a 2-way and 3-lane highway, queue formation of 1 or 2 vehicles per lane can be mentioned. Queues of 1 or 2 vehicles are scenarios that do not constitute a major obstacle for vehicles to accelerate after a red light. However, as the number of stopped vehicles starts to increase as a result of the signaling system at crosswalk, a significant increase in delay values can be observed due to both the number of queues and acceleration.

In cases where a total of 19 or more vehicles were stopped for both directions, it shows that queue formation of 3 or more vehicles occurred on average in each lane on the road with 2 directions and 3 lanes, assuming that the vehicles are equally distributed directionally. When the delay data for these rounds are analyzed, it is found that the Average Waiting Time of Vehicles for South Axis value is higher than the average delay value obtained for all rounds in rounds with queues of 3 or more vehicles. However, the same is not the case for the north axis. In this case, it is thought that the inference that the volume value for the south axis is higher than the north axis, as emphasized earlier, is effective.

In order to determine the state of traffic flow, the distribution of the data obtained according to hours was realized (Fig 12). While examining the pedestrian crossing usage, it was determined that the number of crosswalks used by pedestrians increased during the rush hours of work and school (16.00-18.00). In parallel with the intensity of pedestrian crossing use, the number of vehicles waiting at crosswalks when the red light turns red for vehicles is considerably higher during these hours compared to other time periods.

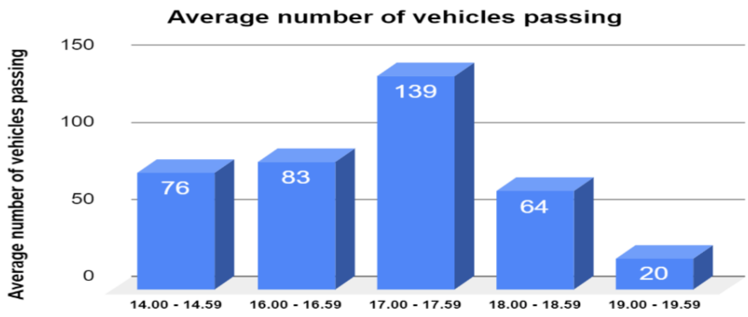

Fig. 12. Average number of vehicles passing

3. Conclusions and recommendations

In this study, pedestrian and driver behaviors at crosswalk with pedestrian push-button signalization control were investigated. In this context, data were obtained by making video recordings on different days and hours at the pilot pedestrian crossing determined in Samsun province. The crossing movements of 227 pedestrians using the crosswalk were analyzed. 165 pedestrians crossed the street using the pedestrian push-button in 67 different rounds. In this process, 791 vehicles in total paused due to the red light in 67 rounds when the pedestrians turned green and the vehicles turned red. In the studies conducted, pedestrians were not evaluated in terms of age and gender. For more comprehensive analysis, a study can be conducted that takes into account biological differences and psychological and behavioral differences in pedestrian behavior. In this way, the effective parameters in pedestrian behavior can be determined.

When the behaviors of pedestrians and drivers were analyzed, the following conclusions were reached.

- Although pedestrians generally use the pedestrian push-button, there are pedestrians waiting without using the button. It is thought that pedestrians may not know how the system works.
- Pedestrians using the button do not wait for the green light to turn green to cross the road, but cross when they find a suitable moment, and vehicles are stopped unnecessarily if the light turns green after crossing.
- If the button is pressed on the median, only one-way passage is provided and traffic is unnecessarily stopped on both axes.
- At one-way crossings, it may be unnecessary to stop traffic for both axes at the same time until the pedestrian reaches traffic island from the starting point.
- Unnecessary stops can create impatience for drivers and a tendency to run red lights.
- The green light duration defined for pedestrians was found to be appropriate based on the required duration calculated based on average pedestrian speeds and pedestrian crossing movements during observations.

In line with the results obtained, the suggestions developed for the system to work more effectively are presented below.

- Authorities should ensure that pedestrians understand the working logic of the system and encourage them to use it when necessary.

- Administrators should take measures to detect the presence of pedestrians in order to prevent unnecessary waiting of vehicles when pedestrians press the button but do not turn green. Simple solutions such as pressing the button or waiting in a defined area with sensors can be used. In addition, a mechanism should be added to make the button inactive in case of abandonment.

- A staggered or independent signal plan for the two axes can prevent unnecessary stops on both axes at the same time. If a button is pressed on the traffic island, pedestrians should be given a green light only for the axis in the direction of travel, not for both directions.

- If the system is used more efficiently, pedestrian safety will increase and unnecessary waiting for vehicles will be eliminated. Thus, decreases in fuel consumption and exhaust emissions can be seen. This is very important to provide a more environmentally friendly transportation infrastructure.

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Author Contributions

Eren Dağlı: Conceived and designed the analysis, Contributed data or analysis tools, Performed the analysis, Wrote the paper.
Ahmet Göktuğ Saraç: Collected the data, Contributed data or analysis tools, Wrote the paper.
Metin Mutlu Aydın: Conceived and designed the analysis, Contributed data or analysis tools, Performed the analysis, Wrote the paper.

References

[1] Kıran, S., Şemin, S., and Ergör, A., Kazalar ve toplum sağlığı yönünden önemi. *Sürekli Tıp Eğitimi Dergisi*, 10(2), 50-1, 2001.
[2] Uyurca, Ö. and Atılgan, İ., Ankara ilinde meydana gelen trafik kazalarının incelenmesi. *Kent Akademisi*, 11(4), 618-626, 2018.
[3] Akgüngör, A. and Doğan, E., Smeed ve Andreassen kaza modellerinin Türkiye uygulaması: Farklı senaryo analizleri. *Gazi Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi*, 23(4), 2008.
[4] Türkiye İstatistik Kurumu, Karayolu Trafik Kaza İstatistikleri 2022, 49513, 2023.
[5] Dağli, E., Aydin, M. M., Çoruh, E., Şehir İçi Ana Arterlerde COVID-19 Kısıtlamalarından Dolayı Trafik Akımlarında Meydana Gelen Değişimlerin İncelenmesi: Antalya Örneği. *İdealkent*, *12*(34), 1199-1225, 2021.
[6] Özen, M., Yaya kazalarının yaralanma şiddetinin incelenmesi: İkili lojistik regresyon modeli uygulaması. *Teknik Dergi*, 32(3), 10859-10883, 2021.
[7] Karayolları Genel Müdürlüğü, Trafik Güvenliği Dairesi Başkanlığı, Trafik Kazaları Özeti 2022, 2023.

[8] Wong, S. C., Sze, N. N. and Li, Y. C., Contributory factors to traffic crashes at signalized ıntersections in Hong Kong. *Accident Analysis and Prevention*, 39(6), 1107-1113, 2007.

[9] Mahmud, M.S., Pedestrian crossing behavior at intersections and existing walking facilities in Dhaka metorpolitan city, Bachelor Thesis, *Bangladesh University Engineering and Techonology Faculty*, 2015.

[10] https://www.slc.gov/transportation/walking/, [Accessed: Jan. 10, 2024].

[11] https://sinyalizasyon.com.tr/sinyal-yaya-butonu-syb06, [Accessed: Jan. 10, 2024].

[12] https://robertdyer.blogspot.com/2022/07/do-drivers-obey-pedestrian-crosswalk.html, [Accessed: Jan. 10, 2024], 2022.

[13] Sarısoy, G., Polat, A., Tezcan, H. O., Tramvay istasyonu erişimindeki işikli yaya geçidi ihlallerinin irdelenmesi, *TMMOB Elektrik Mühendisleri Odası, İnşaat Mühendisleri Odası, Makina Mühendisleri Odası Raylı Sistemler Kongre ve Sergisi,* Eskişehir, Türkiye, 2023.

[14] Alkan, İ. N., Yeşil, M., yürünebilirlik kavramı ve çevresel faktörler odağında yaya kullanımı: Ordu - Akyazı mahallesi örneği. *Akademik Ziraat Dergisi*, 11(2), 383-396, 2022.

[15] Önelçin, P., Alver, Y., Üst geçit bölgelerinde kural dışı geçiş yapan yaya davranışlarının irdelenmesi ve yürüyen merdivenin üst geçit kullanım oranına etkisi. *Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi*, 24(6), 1100-1106, 2018.

[16] Uysal, M. and Alver, Y., Yükseltilmiş yaya geçidinin lise çağındaki yayaların kabul edilebilir aralık seçimine etkisi. *Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi*, 27(3), 342-348, 2020.

[17] Feliciani, C., Gorrini, A., Crociani, L., Vizzari, G., Nishinari, K., Bandini, S., Calibration and validation of a simulation model for predicting pedestrian fatalities at unsignalized crosswalks by means of statistical traffic data. *Journal of Traffic and Transportation Engineering*, 7(1), 1-18, 2020.

[18] Pineda-Jaramillo, J., Barrera-Jiménez, H., Mesa-Arango, R., Unveiling the relevance of traffic enforcement cameras on the severity of vehicle–pedestrian collisions in an urban environment with machine learning models. *Journal of Safety Research*, 81, 225-238, 2022.

[19] Sahu, P. K., Maji, A., Nath, B., Roh, H. J., Questionnaire based study of drivers' error and violation at four-legged signalized intersection. *Transportation Letters*, 2021, 1-12, 2021.

[20] Ewing, R. and Dumbaugh, E., The built environment and traffic safety: A review of empirical evidence. *Journal of Planning Literature*, 23(4), 347-367, 2009.

[21] Gitelman, V., Carmel, R., Pesahov, F., Evaluating ımpacts of a leading pedestrian signal on pedestrian crossing conditions at signalized urban ıntersections: a field study. *Frontiers in Sustainable Cities*, 2(45), 1-12, 2020.

[22] Li, R. He, Y. L., T., Li, L., Schwebel, D. C., Huang, H. L., Yin, Q. Y., Hu, G. Q., Left-turning vehicle-pedestrian conflicts at signalized intersections with traffic lights: Benefit or harm? A two-stage study. *Chinese journal of traumatology*, 22(2), 63-68, 2019.

[23] Simeunović, M., Jović, A., Pitka, P., Dobrić, M., The Impact of Uncertainty on Pedestrians' Decision to Start Roadway Crossing during the Clearance Phase. *Complexity*, 2021, 1-14, 2021.

[24] Hatfield, J., Fernandes, R, Job, R. F. S., Smith, K., Misunderstanding of Right-Of-Way Rules at Various Pedestrian Crossing Types: Observational Study and Survey. *Accident Analysis & Prevention*, 39(4), 833-842, 2007.

[25] Yaman, T., Dağlı, E., Aydın, M. M., Keleş, M. A., Fasılalı Geçiş Sistemlerinde Güvenli Geçiş Uygulamaları. *İdealkent*, 13(36), 797-823, 2022.

[26] Hamed M., Analysis of pedestrians' behavior at pedestrian crossing. *Safety Science*, 38, 63-82, 2001.

[27] Kadali R, Rathi N, Perumal V., Evaluation of pedestrian mid-block road crossing behaviour using artificial neural network. *Journal of Traffic and Transportation Engineering*, (2), 111-119, 2014.
[28] Yannis G, Apadimitriou E., Theofilatos AA, pedestrian gap acceptance for mid-block street crossing, *WCTR 2010 World Conference on Transport Research Society*, Lisbon, Portugal, 2010.
[29] Liu Y and Tung C., Risk analysis of pedestrians' road crossing decisions, effects of age, time gap, time of day, vehicle speed. *Safety Science*, 63, 77-82, 2014.
[30] L. Hell, J. Sprenger, M. Klusch, Y. Kobayashi, C. Müller, Pedestrian behavior in Japan and Germany: A Review, *IEEE Intelligent Vehicles Symposium (IV)*, Nagoya, Japan, 2021.
[31] İ. Küçükali, Understanding Pedestrian Road Crossing Behavior, Bachelor Thesis, *The Graduate School of Social Sciences Of Özyeğin University*, 2020.
[32] Faisal, A. R., Kent Merkezi Ana Arter ve Kavşak Yaklaşımında Yaya Geçiş Davranışının İncelenmesi, Bachelor Thesis, *Süleyman Demirel Üniversitesi Fen Bilimleri Enstitüsü*, 2019.
[33] Kruszyna, M., Jeremi Rychlewski, J., Influence of approaching tram on behaviour of pedestrians in signalised crosswalks in Poland. *Accident Analysis & Prevention*, 55 185-191, 2013.
[34] Tiwari, G., Bangdiwala, T., Saraswat, A., Gaurav, S., Survival analysis: Pedestrian risk exposure at signalized intersections. *Transportation Research Part F*, 10(2), 77–89, 2007.
[35] Lavalette, B.C., Tijus, C., Poitrenaud, S., Leproux, C., Bergeron, J., Thouez, J.P., Pedestrian crossing decision-making: a situational and behavioral approach. *Safety Science*, C47(9), 1248–125, 2009.
[36] https://yandex.com.tr/harita, [Accessed: Jan. 11, 2024].
[37] https://www.google.com/maps, [Accessed: Jan. 10, 2024].
[38] Emniyet Genel Müdürlüğü, Trafik İstatistik Bülteni Kasım 2023, 2023.
[39] Saplıoğlu, M., Faisal, A. R., Sinyal kontrollü ve kontrolsüz kesimlerde yayaların karşıdan karşıya geçiş davranışlarının değerlendirilmesi. *Gümüşhane Üniversitesi Fen Bilimleri Dergisi*, 10(2), 309-320, 2020.
[40] Highway Capacity Manual, Transportation Research Board National Research Council; 2010, 2010.