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USING SWARA METHOD FOR EVALUATION OF FACTORS AFFECTING PEDESTRIAN SAFETY AT INTERSECTIONS

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ABSTRACT

Intersections are considered among the most hazardous points in traffic and can pose significant dangers, especially for pedestrians. The primary aim of this study is to investigate factors affecting pedestrian safety at intersections and to develop effective strategies to enhance pedestrian safety. In this context, various factors influencing pedestrian safety at intersections need to be considered. Within the scope of the research, factors such as pedestrian speed, vehicle speed, traffic signs and signals, intersection geometry, signaling systems, road surface, traffic volume, illegal parking, weather and lighting conditions, pedestrians' ages and clothing choices have been identified as key elements affecting pedestrian safety at intersections. These criteria have a wide range of impacts on traffic safety. The SWARA method was used to determine the priority order of these criteria. As a result of this analysis, vehicle speed was identified as the most significant factor, while pedestrian clothing choice was determined to be the least important factor. Based on the analysis of these criteria, appropriate measures can be taken to ensure safe pedestrian crossings. In conclusion, a holistic approach must be adopted to enhance pedestrian safety. This entails considering all factors affecting pedestrian safety at intersections and developing appropriate strategies. This approach can lead to more effective solutions to intersection safety issues and ensure pedestrian safety.

1 INTRODUCTION

Road transportation has brought many problems in parallel with the increasing population. Considering the economic and environmental losses due to the increase in traffic density in metropolitan and metropolitan areas, it is observed that the focus of the problems is the intersections [1]. Intersections, which are the separation and joining points of highways, are the most important elements of the road network that ensure the safe transfer of traffic flow. They are critical points in terms of accident risk. When traffic accidents are analyzed, it is seen that intersections play a major role and it has been examined that they pose a hazard to the safety of pedestrians.

There are three basic factors in traffic accidents: human, vehicle and environment (road). Human beings are at the top of these elements. Pedestrians, known as the most vulnerable road users, have always been seriously affected by accidents [2]. More than 1/5 of the people who die on highways around the world die as pedestrians. In order to protect pedestrians and ensure safe travel, understanding the risk factors in pedestrian crashes and successful interventions are required. In this context the parameters that can affect pedestrian safety at critical intersections have been determined as a result of the necessary investigations. The higher the speed at which the vehicle is traveling, the higher the risk of hitting the pedestrian and the vehicle. Likewise, the higher and uncontrolled the pedestrian's speed, the greater the risk of an accident as it will affect the vehicle's road and stopping distance relationship. Another important factor that affects the safe and orderly flow of traffic by directing pedestrians and drivers correctly in traffic is traffic signs and traffic sign boards [3]. The fact that the traffic sign boards are adequate and in accordance with the standards and their meanings are known by road users will positively affect pedestrian safety at intersections [4]. Intersections can be configured in different ways according to their geometric characteristics. Roundabouts are preferred more than level intersections in terms of traffic and pedestrian safety.

Signalization applications are one of the important factors that positively affect pedestrian safety by ensuring the regular flow of traffic at intersections, which are key points of traffic [5]. The road is the foundation of traffic. For this reason,

the geometric characteristics of the road are important for the safety of traffic and pedestrians. The pavement type of the road is affected by climatic conditions and traffic load depending on whether it is flexible or rigid. Deformations such as wheel tracks, holes, settlements and undulations on the road pavement will increase the risk of accidents [6]. Heavy traffic volume will negatively affect pedestrian travel. This reduces the safety of the pedestrian. Misparking negatively affects the traffic in motion and the pedestrian's travel passage.

When the weather is good and road conditions are favorable, the risk of fatal accidents is higher otherwise, the risk of fatal accidents is lower. In addition, more vehicles are on the road when the weather is clear and fewer vehicles are on the road when the weather is bad. On slippery surfaces with bad weather, the grip force of the tires will decrease, vehicles will start to slip and the risk of accidents will increase. Therefore, the density of traffic volume is considered negative for the safety of pedestrians at intersections [7]. The fact that daytime travel is higher than nighttime endangers safety due to the volume of traffic. The speed of pedestrians is affected by their gender and age. As age increases, crossing speeds decrease [8-16]. Young adults and younger pedestrians tend to violate the rules more than pedestrians in other age groups [17-18]. As drivers, young people are also more prone to errors than older individuals. Pedestrians' choice of light-colored clothing has a negative impact on safety as it increases the time it takes for daytime drivers to notice and react. Pedestrians' choosing dark-colored clothes more is among the precautions to be taken against a possible accident.

This study presents an MCDM approach to examine the factors affecting pedestrian safety at intersections and to develop strategies to improve pedestrian safety. SWARA method is used as an MCDM approach. Based on the literature, 12 criteria affecting pedestrian safety at intersections are evaluated by SWARA method. In the evaluation process, expert opinions form the basis for the analysis method. According to Zavadskas et al. the advantages of the SWARA method are primarily seen in the fact that there are far fewer comparisons compared to other criteria and that experts' opinions on the importance of the criteria are evaluated in the process of determining the weights of the criteria. Thanks to these features, this method is applied in many different fields.

Following this introduction, the article is divided into five sections. The next section presents a brief summary of the literature on pedestrian safety at intersections, while Section 3 provides a brief description of the material and the methodology used in the study. Section 4 summarizes the analysis results of the SWARA method and Section 5 summarizes the main conclusions of this study.

Edigbe et al. [19] aimed to determine the level of service of signalized intersections on the highway. In the study, average delay was used as intersection performance parameter. As a result of the analysis, it was found that the absence of signals at roundabouts effectively reduces intersection congestion and conflicts and improves the level of service. Wang et al. [20] and Muffert et al. [21] stated in their studies that geometric features can be of great benefit when analyzing traffic safety and driver behavior at roundabouts.

In their study, Öksüz and Eyigün [22] addressed the problems of Bahçelievler Ünverdi Intersection in Istanbul and proposed projects related to the existing geometry of the intersection. In his study, Montella [23] states that at least one geometric factor is effective in 60% of the total accidents at roundabouts. This finding suggests that the design of geometric elements at roundabouts plays a critical role in traffic safety. The aim of this review study is to analyze the relationship between roundabout geometric elements and safety performance in the light of the research conducted to date. It also evaluated the situation in Turkey and the motivation for this study was motivated by the lack of previous detailed studies on the subject.

Murat and Çakıcı [4] investigated whether the drivers in Denizli have sufficient knowledge and awareness about traffic signs and signals. The 27 traffic signs and signals that are frequently encountered in daily life were selected and a questionnaire consisting of 27 questions was created for 500 people who drive vehicles. According to the evaluations, it was observed that 40% had medium, low and very low level of awareness and 25% of the traffic signs had very high level of awareness. This situation was evaluated negatively in terms of traffic signs and markings. If the public is not sufficiently aware of traffic signs and markings, accidents will be inevitable. In this context, public awareness should be raised through education and mass media.

Quddus et al. [24] combine the sequential response model with econometric analysis to investigate the relationship between road traffic safety and crash severity. In this study, other contributing factors were controlled for when examining crash records and a traffic density measure was used with non-clustered crash data. This study highlights the importance of using sequential response models and econometric analysis in the field of road traffic safety.

2 MATERIAL AND METHOD

2.1 Material

Pedestrians are the most vulnerable group in traffic accidents and intersections are particularly risky areas for pedestrians. In this context, this study examines various factors affecting pedestrian safety at intersections. The criteria used in the study include twelve different criteria: pedestrian speed (C1), vehicle speed (C2), traffic sign boards (C3), intersection geometry (C4), signalization (C5), pavement type (C6), traffic volume (C7), misparking (C8), weather condition (C9), day status (C10), pedestrian age (C11), pedestrian's choice clothing (C12 (Figure1)).

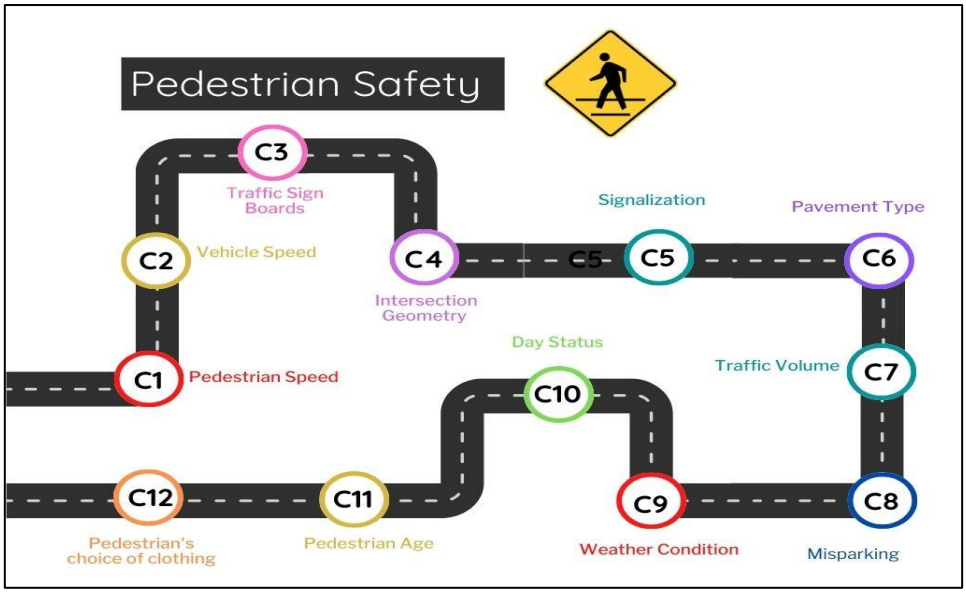

***Figure 1**. The criteria used in the study*

2.2 Method

SWARA (Step-wise Weight Assessment Ratio Analysis) method, one of the Multi-Criteria Decision Making (MCDM) method, was used in the study. For the analysis, literature reviews and expert opinions (a group consisting of 4 academicians and 1 master engineer in transportation engineering) were used. In the interviews with the experts, they were asked to rank the importance of the criteria used in the study in terms of pedestrian safety at intersections and according to this ranking, their opinions were obtained about how much more important each criterion is than the previous criterion. In this study, SWARA method was used in Microsoft Excel. SWARA method was applied for weighting the criteria. A brief description of the method used is given below.

2.3 SWARA (Step-wise Weight Assessment Ratio Analysis) Method

SWARA method is one of the methods for determining weight values that play an important role in the decision-making process [25]. SWARA is a multi-criteria decision-making (MCDM) method that is simple and highly suitable for working with experts. SWARA is an effective tool in complex decision-making processes and performs a step-by-step analysis to determine the weights of various criteria and alternatives. In this method, the opinions of experts play an important role in the calculation of criteria weights [26-27]. Figure 2 shows the flowchart of this study.

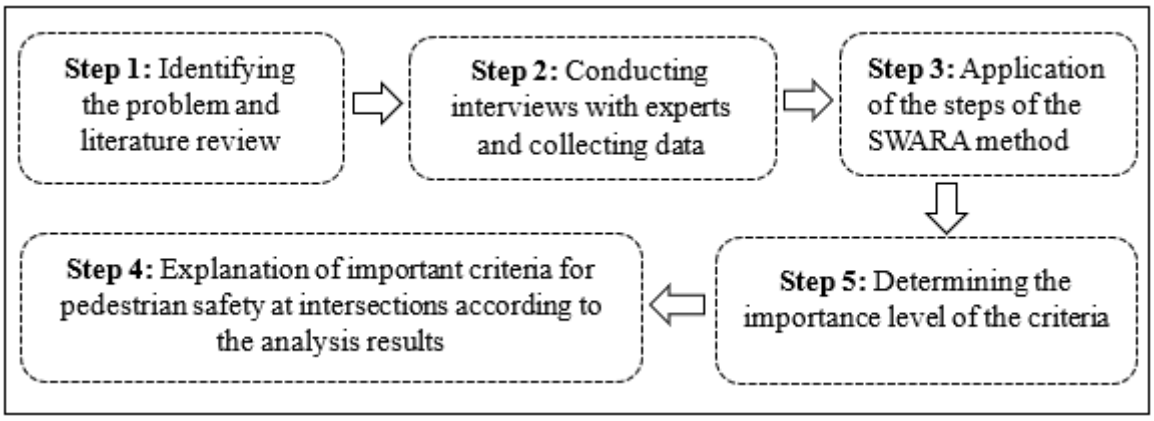

***Figure 2**. The flowchart of this study*

The process of determining criterion weights is presented in Figure 3.

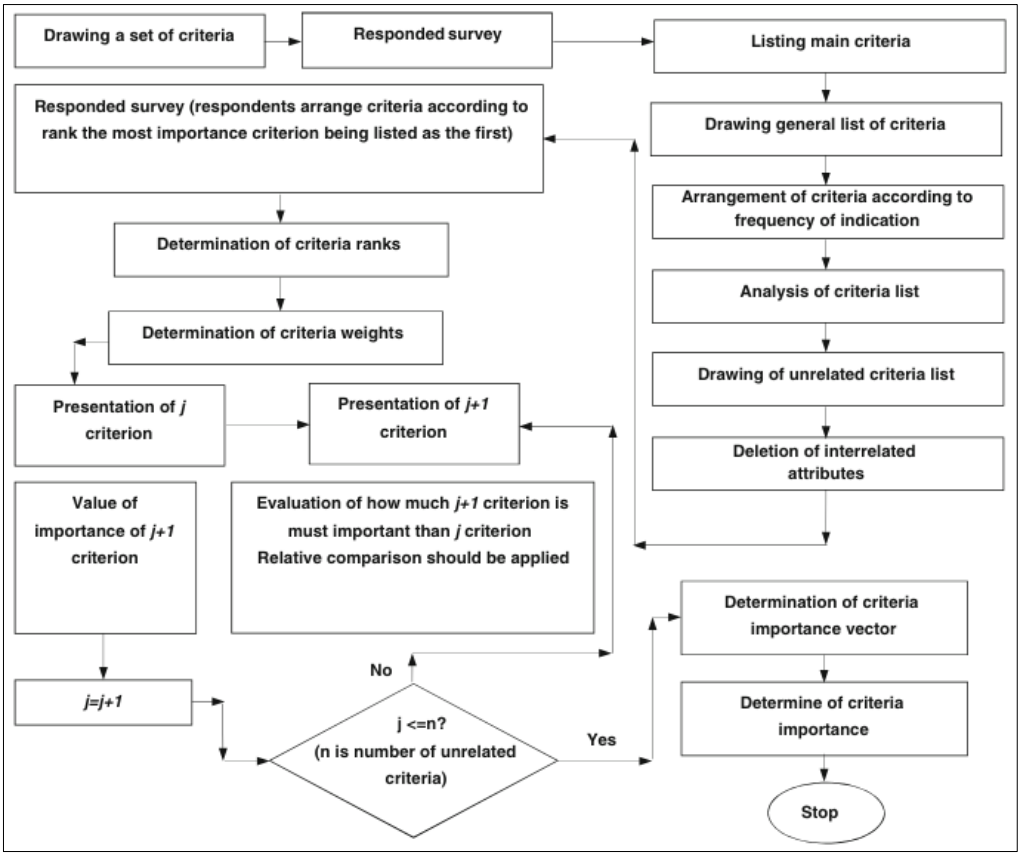

***Figure 3**. The proposed flowchart of the SWARA method [26]*

The steps of the relative weighting process of criteria using the SWARA method are listed below [28].

Step 1: The criteria are simply listed in descending order of importance in line with expert opinion. If more than one expert will evaluate the criteria, the criteria are ranked in descending order as a result of the evaluation made by each expert, and a general ranking is created by taking the geometric mean of the criteria [29].

Step 2: The relative importance of each criterion is determined. For this (j+1). with criterion j. By comparing criteria; j. criterion (j+1). The importance of the criterion is expressed as a percentage. This value was determined by Kersuliene et al. [26] denoted by sj and called 'comparative importance of the average value'.

Step 3: The kj coefficient is determined as in equation 1.

$$k_j = \begin{cases} 1 & j = 1 \\ sj + 1 & j>1 \end{cases} \quad (1)$$

Step 4: qj variable is calculated with the equation in equation 2.

$$q_j = \begin{cases} 1 & j = 1 \\ \dfrac{qj-1}{kj} & j>1 \end{cases} \quad (2)$$

Step 5: The relative weights of the evaluation criteria are determined by equation 3. Here wj, j. indicates the relative weight of the criterion.

$$w_j = \frac{qj}{\sum_{k=1}^{n} qk} \quad (3)$$

3 RESULTS AND DISCUSSION

The weighting of the criteria affecting pedestrian safety at intersections was determined using SWARA by establishing a decision-maker team of 5 from experts in the fields and the authors, as well as examining the literature. In the interviews with the decision makers (DM), they were first asked to rank the importance of the criteria affecting pedestrian safety at intersections. Then, they were asked to compare how much more important the criteria are in percentage terms than the next criterion in the ranking they determined. As a result of the interview, the importance rankings of the criteria and the comparative importance of the average value (sj) variable were obtained from the DM and the data set was created (Table 1). For the criteria in the data set (C1, C2, C3, C4, C5, C6, C7, C8, C9, C10, C11 and C12), kj and qj variables were calculated for each DM using Equation 1 and Equation 2 in the steps of SWARA method. Then, the relative weights of the criteria were calculated using Equation 3 (Table 1).

For example, decision maker-1 ranked the criteria as C2-C4-C7-C5-C8-C3-C1-C11-C9-C10-C6-C12 in descending order of importance starting from the most important criterion. According to DM-1, the most important criterion for pedestrian safety is C2, while the least important criterion is C12. Then, in order to determine the comparative importance of the average value (sj), DM-1 compared each criterion with the preceding criterion, such as the 2nd ranked criterion with the 1st ranked criterion, the 3rd ranked criterion with the 2nd ranked criterion, starting with the

2nd ranked criterion. DM-1 stated that C4 is 30% more important than C2 (Table 1). Table 1 shows the importance rankings and sj values of the criteria collected from the other DM in the same way. In order to determine the criteria weights (wj), kj and qj values are calculated using the equations given in the steps of SWARA method and given in Table 1.

***Table 1**. Criteria ranking obtained from decision makers and SWARA method variables*

DM1	**Criteria**	**C2**	**C4**	**C7**	**C5**	**C8**	**C3**	**C1**	**C11**	**C9**	**C10**	**C6**	**C12**
	Order of	1	2	3	4	5	6	7	8	9	10	11	12
	sj		0,3	0,2	0,1	0,15	0,2	0,1	0,05	0,25	0,1	0,1	0,2
	kj	1	1,3	1,2	1,1	1,15	1,2	1,1	1,05	1,25	1,1	1,1	1,2
	qj	1	0,76	0,64	0,58	0,50	0,42	0,38	0,36	0,29	0,26	0,24	0,20
	wj	0,17	0,13	0,11	0,10	0,08	0,07	0,06	0,06	0,05	0,04	0,04	0,03
DM2	**Criteria**	**C2**	**C4**	**C7**	**C5**	**C3**	**C6**	**C8**	**C1**	**C11**	**C9**	**C10**	**C12**
	Order of	1	2	3	4	5	6	7	8	9	10	11	12
	sj		0,20	0,15	0,10	0,10	0,30	0,10	0,25	0,20	0,20	0,10	0,20
	kj	1,00	1,20	1,15	1,10	1,10	1,30	1,10	1,25	1,20	1,20	1,10	1,20
	qj	1,00	0,83	0,72	0,65	0,59	0,46	0,41	0,33	0,27	0,23	0,21	0,17
	wj	0,16	0,14	0,12	0,11	0,10	0,07	0,07	0,05	0,04	0,03	0,03	0,03
DM3	**Criteria**	**C2**	**C4**	**C3**	**C5**	**C1**	**C11**	**C8**	**C7**	**C6**	**C9**	**C10**	**C12**
	Order of	1	2	3	4	5	6	7	8	9	10	11	12
	sj		0,15	0,2	0,1	0,1	0,05	0,1	0,1	0,2	0,1	0,3	0,2
	kj	1	1,15	1,2	1,1	1,1	1,05	1,1	1,1	1,2	1,1	1,3	1,2
	qj	1	0,87	0,72	0,65	0,59	0,57	0,51	0,47	0,39	0,35	0,27	0,22
	wj	0,15	0,13	0,10	0,09	0,09	0,08	0,07	0,07	0,05	0,05	0,04	0,03
DM4	**Criteria**	**C2**	**C7**	**C5**	**C4**	**C3**	**C8**	**C6**	**C1**	**C11**	**C9**	**C10**	**C12**
	Order of	1	2	3	4	5	6	7	8	9	10	11	12
	sj		0,3	0,2	0,15	0,1	0,1	0,1	0,1	0,2	0,1	0,2	0,25
	kj	1	1,3	1,2	1,15	1,1	1,1	1,1	1,1	1,2	1,1	1,2	1,25
	qj	1	0,76	0,64	0,55	0,50	0,46	0,41	0,38	0,31	0,28	0,24	0,19
	wj	0,17	0,13	0,11	0,09	0,08	0,08	0,07	0,06	0,05	0,05	0,04	0,03
DM5	**Criteria**	**C2**	**C5**	**C4**	**C9**	**C6**	**C3**	**C7**	**C1**	**C11**	**C12**	**C10**	**C8**
	Order of	1	2	3	4	5	6	7	8	9	10	11	12
	sj		0,3	0,25	0,05	0,7	0,15	0,1	0,45	0,7	0,15	0,4	0,75
	kj	1	1,3	1,25	1,05	1,7	1,15	1,1	1,45	1,7	1,15	1,4	1,75
	qj	1	0,76	0,61	0,58	0,34	0,3	0,27	0,18	0,11	0,09	0,06	0,03
	wj	0,22	0,17	0,14	0,13	0,07	0,06	0,06	0,04	0,02	0,02	0,01	0,00

Table 2 shows the weights calculated for each criterion for each DM using equation 3. For example, according to DM-2, the weight of criterion C2 is the highest, while the weight of criterion C12 is the lowest. According to DM-5, the weight of criterion C2 is the highest while the weight of criterion C8 is the lowest. Using the

weights obtained according to the DM, the importance ranking was made for each criterion by taking the geometric mean of these weights (Table 2).

***Table 2**. Importance ranking of criteria*

Criteria	Decision Maker-1	Decision Maker-2	Decision Maker-3	Decision Maker-4	Decision Maker-5	Final Criteria Weights	Ranking
C1	0,068	0,057	0,090	0,066	0,043	0,063	7
C2	0,176	0,169	0,150	0,173	0,228	0,177	1
C3	0,074	0,101	0,109	0,088	0,068	0,087	5
C4	0,136	0,141	0,130	0,097	0,140	0,128	2
C5	0,103	0,111	0,099	0,111	0,175	0,117	3
C6	0,043	0,078	0,059	0,073	0,079	0,065	6
C7	0,113	0,122	0,071	0,133	0,062	0,096	4
C8	0,089	0,071	0,078	0,080	0,009	0,051	10
C9	0,052	0,039	0,054	0,050	0,133	0,059	8
C10	0,047	0,036	0,041	0,042	0,016	0,034	11
C11	0,064	0,047	0,086	0,055	0,025	0,051	9
C12	0,036	0,030	0,034	0,033	0,022	0,031	12

Table 2 shows the weights of the criteria affecting the affecting pedestrian safety at intersections. As a result of the weighting, the most important criterion was C2-vehicle speed. The least important criterion was the C12-pedestrian's choice of clothing. The order of importance was C2-C4-C5-C7-C3-C6-C1-C9-C11-C8-C10-C12.

This study seems to examine a set of criteria using the SWARA method to evaluate pedestrian safety at intersections. According to the literature review, similar comprehensive studies that assess pedestrian safety by integrating such a multitude of criteria are rarely encountered. This may underscore a significant advantage of the selected criteria and the SWARA method. The results suggest that both the selected criteria and the country-specific conditions could contribute positively to the literature. This study could be a valuable resource for researchers aiming to develop more effective strategies to enhance pedestrian safety at intersections.

4 CONCLUSION AND SUGGESTIONS

Traffic accidents, one of the problems brought about by the developing and changing world, cause millions of people to lose their lives every year. Most of these accidents occur at intersections and this situation poses a serious risk, especially for pedestrians, who are the most vulnerable group in accidents. Intersections are the most intense points of interaction between vehicles and pedestrians. Pedestrian safety has a key role in preventing traffic accidents. It is of great importance to ensure pedestrian safety at intersections for the safety of both pedestrians and other road users. Therefore, identifying and prioritizing criteria to improve pedestrian safety at intersections is an important step.

In the study, the criteria affecting the safety of pedestrians at intersections were determined as a result of literature reviews and ranked by SWARA method by taking the opinions of experts. The study includes twelve different criteria such as pedestrian speed, vehicle speed, traffic sign boards, intersection geometry, signalization, pavement type, traffic volume, misparking, weather condition, day status, pedestrian's age, pedestrian's choice of clothing. According to the results of the analysis obtained by applying the SWARA method, the order of these criteria starting from the most important one is; vehicle speed, intersection geometry, signalization, traffic volume, traffic signs and markings, pavement type, pedestrian speed, weather, pedestrian's age, pedestrian's age, misparking, day condition and pedestrian's choice of clothing. The selection of these criteria highlights the main objective of the study, which is to improve pedestrian safety at intersections. These choices aim to play a pioneering role in the field and represent an exemplary approach to intersection safety. Strategies and measures that can be implemented to improve pedestrian safety at intersections:

- Individuals can be educated from an early age to increase knowledge and awareness about traffic.
- Reviewing the geometry of intersections, the location of pedestrian crossings and signage is important to improve pedestrian safety. In particular, pedestrian crossings should be clear and distinct, pedestrian crossings should be widened, safe pedestrian zones should be created at intersections and pedestrians should be given priority.

- Awareness can be raised by providing information about traffic in mass media.
- Speed-breaking measures should be taken when approaching intersections to keep vehicle speeds under control. Signalization systems should be installed and actively used at specific and needed intersections.
- Traffic signs and markings should be actively used to keep traffic in a regular and safe flow.
- With the use of sensors at intersections and the integration of smart traffic systems, new technological solutions can be developed for pedestrian safety. For example, warning systems can be installed for the presence of pedestrians at the intersection.

As a result, sustainable solutions should be proposed to increase pedestrian safety at intersections and cooperation should be established with the necessary stakeholders to implement the solutions. Thus, important steps will be taken to reduce traffic accidents and ensure pedestrian safety.

Conflict of Interest Statement

There is no conflict of interest between the authors.

Authors Contributions

Nuriye Kabakuş: Investigation, Methodology, Writing - original draft, Writing - review & editing, Visualization.

Merve Eyüboğlu: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Writing - original draft, Writing - review & editing.

Statement of Research and Publication Ethics

The study is complied with research and publication ethics.

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