

TDK THESIS

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**Analysis of Speed Profiles of Vehicles Approaching Visible (Smart)
Pedestrian Crossings**

Declaration of originality

I, the undersigned Murad Al Khayyat a student of Széchenyi István University, declare that the diploma thesis entitled Analysis of Speed Profiles of Vehicles Approaching Visible (Smart) Pedestrian Crossings is my own work and that I have used only the cited sources to the extent indicated, in accordance with the rules of citation, with the exact indication of the references.

My results are based on my own work, calculations, research, measurements, and are authentic to the best of my knowledge.

Győr 2024, 04, 02nd

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Abstract

Analysis of Speed Profiles of Vehicles Approaching Visible (Smart) Pedestrian Crossings

Murad Al Khayyat

The integration of intelligent pedestrian crossings represents a pragmatic shift in contemporary road safety infrastructure, welcoming a new era of enhanced pedestrian protection and interaction within urban environments. This thesis delves into the comparative analysis of speed profiles of vehicles approaching traditional pedestrian crossings versus intelligent crossings, with a specific focus on the SafeXOne system by VisibleCrossing. Through a comprehensive literature review, this study explores the nuanced relationship between vehicle speeds and pedestrian safety, the efficacy of traditional versus intelligent pedestrian crossings, and the unique features and functionalities of the SafeXOne system. Methodologically, data collection encompasses vehicle speed profiles before and after the installation of intelligent crossing and how does it affect a whole segment of the road. Statistical analysis, including ANOVA and regression analysis, are employed to evaluate safety outcomes and efficiency. The research objectives are cantered on assessing risks associated with speed profiles near pedestrian crossings, identifying patterns in pedestrian crossing behaviour and vehicle speed profiles, and analysing the impact of intelligent crossings on overall road safety. Findings indicate that intelligent pedestrian crossings, particularly the SafeXOne system, demonstrate superior safety outcomes and efficiency compared to traditional crossings, showcasing the potential of smart infrastructure to optimize road safety measures. The study underscores the transformative impact of intelligent crossings in fostering safer urban spaces and offers valuable insights for policymakers, urban planners, and transportation engineers seeking evidence-based strategies to enhance pedestrian safety.

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Chapter 1. Introduction:

1.1. Background:

Road safety is the utmost responsibility of an infrastructure engineer, as we are living in a landscape of modern urban living, we emphasize safeguarding all road users. A vital component of this concern is pedestrian crossings, which are a component of the urban transportation system. Pedestrian crossings are designed to establish safe interactions between road users (Pedestrians, Cyclists, and Vehicular traffic). When we mention pedestrian crossings, a simple question comes to our mind, what is their effectiveness and how is it related to the speed profiles of approaching vehicles?

Pedestrian crossings serve as safe conduits for pedestrian movement; however, they face challenges related to the speed profiles of approaching vehicles. The high speeds near these crossings increase the risk of pedestrians' safety and accidents. The imperative to enhance the safety of pedestrians prompts us to explore more innovative solutions, one of which is to leverage the upgrowing Artificial Intelligence and integrate it with the pedestrian crossing infrastructure we already have.

These systems offer a dynamic approach to augmenting pedestrian safety. By employing sensors to analyse the behaviour of pedestrians approaching, it can enhance safety near pedestrian crossings by optimising crossing times and alerting drivers to upcoming pedestrian movement.

VisibleCrossing Ltd. is a pioneer when it comes to intelligent pedestrian crossings. The company launched the prototype of SafeXOne in 2016 and first introduced it to the market in 2019. They installed the first systems in Veszprém and Várpalota. The SafeXOne system is an intelligent pedestrian protection system, that aims to enhance the safety of pedestrians by predicting their movement and switching on the required flashing lights and laser beams, the system works effectively and enhances the features of a crossing section.

This thesis aims to analyse the relationship between the speed profiles of approaching vehicles and the safety of pedestrians using the Visible Pedestrian Crossing (SafeXOne System). Through this journey, we seek to assess potential risks, identify patterns of crossing and speed profiles, and contribute to the researchers' discoveries of AI-driven infrastructure segments to optimize road safety measures.

As researchers, we recognize that the integration of intelligent systems is a futuristic concept, but at the same time, it is a pragmatic and transformative step towards creating safe urban spaces. Our findings hold the promise of influencing evidence-based policies, refining traffic management strategies, and paving the way for safer and more accessible roadways, exemplifying the symbiosis between advanced technologies and fundamental road safety principles.

1.2. Thesis Questions:

- How does the variation of different speed profiles contribute to the safety of pedestrian crossings (Intelligent and Traditional)?

- How does the SafeXOne system compare to traditional pedestrian crossings in terms of safety outcomes?
- What are the factors that contribute to the speed profiles of vehicles approaching pedestrian crossings?
- How does the installation of an Intelligent pedestrian crossing affect the speed profile of vehicles for a complete segment of the road?

1.3. Research Objectives:

The objectives of this research are:

- Assessing potential risks associated with speed profiles near pedestrian crossings.
- Identifying patterns in pedestrian crossing behaviour and vehicle speed profiles.
- Comparing the safety outcomes and efficiency of the SafeXOne system to traditional pedestrian crossings.
- Investigating the factors influencing the speed profiles of vehicles approaching pedestrian crossings.
- Analysing the impact of intelligent pedestrian crossings on the speed profile of vehicles along a complete road segment.

1.4. Research Limits:

While this study aims to add valuable insights, it is only fair to acknowledge limits. The study focuses on Intelligent and traditional pedestrian crossings, limiting the scope to these specific implementations. Moreover, the efficiency of the intelligent pedestrian crossings we have on hand is assessed based on the available data and installations, where the variations in real-world conditions may vary. The research is also confined to the analysis of speed profiles and safety outcomes, with broader implications for traffic management strategies and urban planning left for future exploration.

Chapter 2. Literature Review:

2.1. Introduction:

The literature on road safety emphasizes the role of pedestrian crossing in limiting risks and ensuring secure movement. While safety is in mind with designing the traditional pedestrian crossing, it is not immune to challenges, especially the ones related to the speeds of oncoming vehicles. In response to this challenge, the integration of intelligent pedestrian infrastructure emerged as an innovative solution.

Despite the huge efforts to improve road safety, pedestrian casualties represent a high number of road traffic deaths. Researchers found that pedestrian casualties in 2016 reached a staggering 21.2% of total recorded accident deaths in European Union countries (Costa et al., 2020)

In the year 2020 in Hungary, a total of 460 people were killed. According to the European Commission statistics, the mortality rate is improving year by year, while it is not the best among its European neighbours, it is ranked 17th of 27 in terms of lowest fatalities per million inhabitants. As shown in the figure below, The European average mortality rate per million is 42, whereas the Hungarian indicator is 47

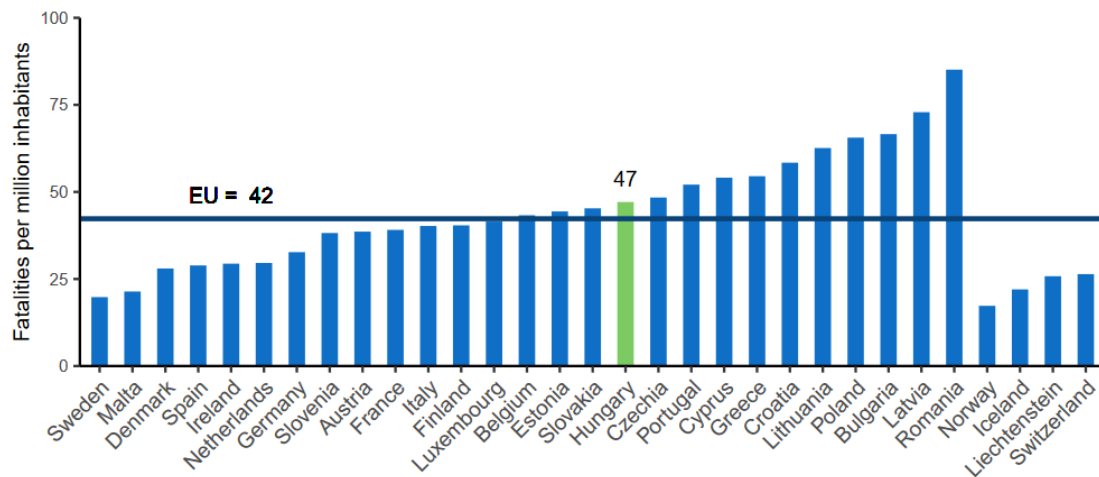


Figure 1: Number of Road Fatalities per Million Inhabitants (European Road Safety Observatory, 2020).

Residential areas are defined with a high flow of pedestrians; thus, it places the safety of pedestrians on a top spot for public health issues. Not all crosswalks should be signalized, whereas, from an operational perspective, it could affect the quality of life in the residential area and produce congestion in the area. Nevertheless, yield-controlled crosswalks are not the safest option due to the risky behaviour of drivers and the low yielding rate of vehicles (Hussain et al., 2023).

In this chapter, we will explore existing literature concerning pedestrian safety; the relationship between vehicle speeds and pedestrian safety, traditional and intelligent pedestrian crossings, and the SafeXOne system and its features.

We begin by analysing studies that provide insights on similar topics, such as the design and functionality of traditional crossings, and then we move to shed light on the promising SafeXOne system by VisibleCrossing. We aim to detect some of the gaps in the existing knowledge and contribute to the optimization of road safety measures using up-to-date technology.

As we dive through this research, our understanding grows that the step towards integrating systems within our road infrastructure is not a speculative concept, but more of a pragmatic and transformative step towards building safer cities. We aim to identify the existing gaps within the literature and help contribute to the safety of pedestrians with this research. This thesis paves the way for a deeper understanding of the difference between the existence of an intelligent pedestrian crossing and a traditional one, and how it contributes to the overall safety of road segments.

2.2. Pedestrian Safety and Traditional Crossings:

Pedestrian crossing is a place (mostly white-striped segments of roads) designated for pedestrians to cross a venue, road, or street. It is an international term, mentioned in the Vienna and Geneva conventions. As per Vienna Convention article 21.2 b, if vehicles are not regulated by signalised traffic lights, or by an authority personnel, drivers shall approach the crossing only at a low speed not to threaten pedestrians using it, or about to use it, and if necessary, they shall stop to give way for pedestrians to cross. The Vienna Convention shows the importance of having a central island in the areas where speed exceeds 30km/hr if feasible, it also states that the speed at pedestrian crossings should be 50 km/hr or less (Vienna Convention, 2002). Moreover, in unfamiliar road alignments where vehicles are designated to make a left turn, the manoeuvring process of turning vehicles is controlled by the priority rule, where pedestrians are given priority over vehicles that are turning left. (Iasmin et al., 2016)

Since we are talking about pedestrian safety, we are due to define the safety meaning and how would we assess it. Traffic conflict analysis method is a method to measure safety for crash data analysis, and it is an alternative for crash data analysis. It is a behaviour-situational aspect of the events, such vital pieces of information are not usually included in the police report in case of an occurrence, thus it is important to understand the relationship between safety and behaviour. This concept was introduced by General Motors in the USA by Harris and Perkins (Perkins and Harris, 1968).

When different road users meet in a place from different directions, the assessment is based on the occurrence of traffic crashes. Although not all crashes are reported, they are considered rare events, in the first international traffic conflict workshop, a definition was set to traffic conflict: “An observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remain unchanged.” (Amundsen and Hydén, 1977)

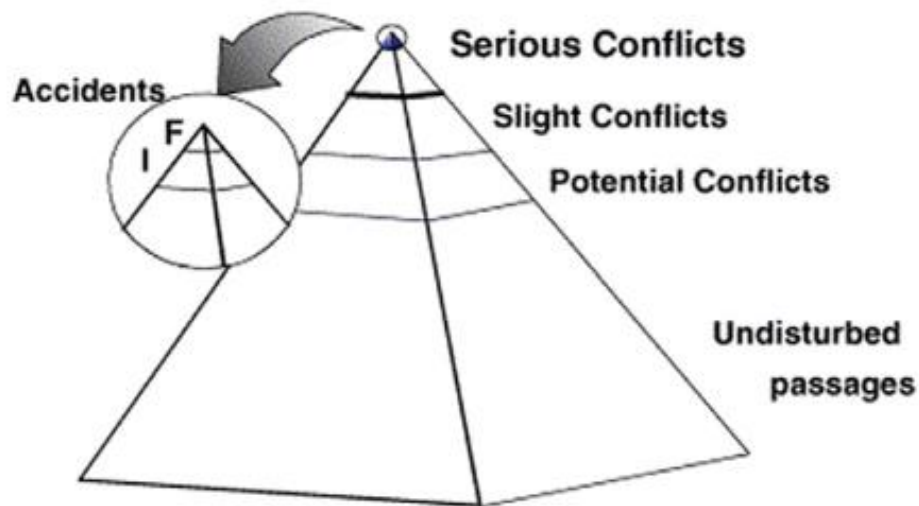


Figure 2: Pyramid of the Interactions Between Road Users as a Continuum of Events (Iasmin et al., 2016)

In the figure, the pyramid shows that the relationship between the road users, which can be described as a continuum of events (Hydén, 1987). As per the previous study, the severity of the conflict can be distinguished based on factors such as the time to accident and conflicting speed when comparing different locations with different geometrical designs (Svensson, 1998).

Walking is considered a sustainable transportation mode; it has recognized ecological and health benefits. Despite the governments' and municipalities' efforts to increase safety, pedestrians are vulnerable users of the infrastructure especially at non-signalized intersections. Thus, it is the high importance to regulate drivers yielding to pedestrians and increase the percentage at non-signalised intersections (Li et al., 2021).

The measures to increase pedestrian safety at an intersection are developing constantly, a list of examples is provided below, including but not limited to:

1. Improving crosswalk design, researchers found that by integrating different approaches such as installing different materials like bricks on a crosswalk or changing the colour of the crosswalk (to red) had a positive impact on safety especially for left turning vehicles, where drivers accept smaller gaps for pedestrians to cross less frequently, this approach

also affected the alertness level of drivers and made them more alert at the earlier stages of entering the crosswalk.

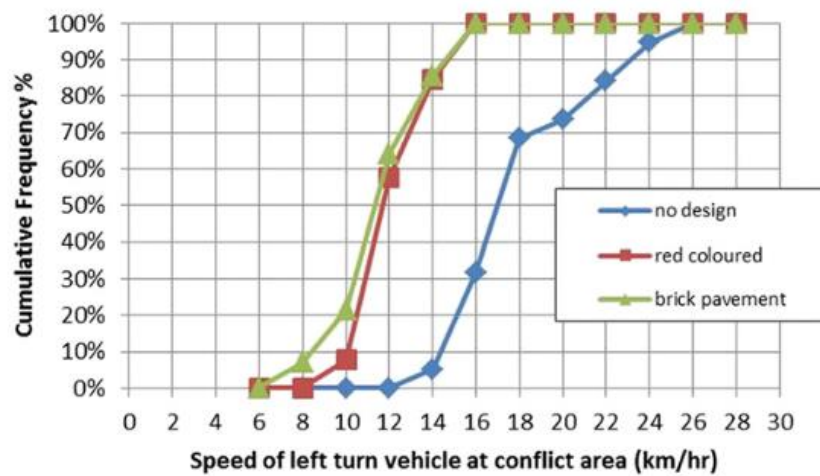


Figure 3: Cumulative Distribution of Vehicle Speeds for Different Pavement Designs.

In the figure above, the researchers did a comparison between red coloured design, brick pavement design and the traditional crosswalk using the cumulative frequency of the recordings they collected, after analysing the data, they noticed a huge improvement in the areas where the designs were implemented by noticing lower speed profiles for the turning vehicles because drivers notice a different visual effect. (Iasmin et al., 2016).

2. Integration of pedestrian refuge island; is a median with a refuge area that is intended for pedestrians to focus on one side of the road at a time. The idea is the combination of multiple lanes of traffic and long crossing distances would create a less safe environment for pedestrians, by reducing the distance and providing a safe refuge for pedestrians this design can reduce pedestrian crashes by 32%.



Figure 4: Refuge Island Design with Reflective Signs and Mounted Signs.

The figure above shows a median island design, the considerations of designing an important infrastructure that it should be bright with streetlights or illuminated, equipped with reflectors to ensure visibility and the necessity for a disability inclusive design. Refuge islands are highly desirable to be used on road with four or more, and a viable treatment option for jaywalking in high speeds or high volumes 3-lane or 2-lane roads, and just like the new vision for designs.

3. Installation of aiding signs and devices. Researchers found that the installation of pedestrian warning systems for crosswalk, flashing devices and side-mounted signs may increase the pedestrian safety, for example (Costa et al., 2020) found in their research results that unified light-warning systems installed on crosswalks boosted the numbers of drivers yielding to pedestrians in dusk times, where the study was assessing seven different conditions of lighting, the overall result was a satisfying increase from (19-38.21%) to (38.21-63.56%) using flashing beacons and LED strips, and it was very effective at night time.

2.3. Dynamics of Road User Interaction at Crossings:

Existing literature reveals a wide variety of factors influencing pedestrian safety. In this chapter, we aim to provide an overview of the dynamics of factors observed at pedestrian crossings that would contribute positively or negatively to pedestrian safety. These complex interactions among pedestrians, cyclists and motorized traffic vary between behavioural according to the human nature's psychology and biology, geometric considerations, installation of aiding devices and implementation of safety measures. As per (Li et al., 2021), pedestrian Safety are affected by the following factors, pedestrian, vehicular and environmental factors.

2.3.1. Pedestrian Characteristics

Pedestrian characteristics delves into the physical and physiological characteristics of pedestrians, showing how such characteristics contribute to their safety. Research showed that elderly would be subjected to more risk, as a result of the decrease in cognitive performance and mobility, and also because of their risky overpassing behaviour as having less start-up times (time required to start moving which is average 3 second), less head movement and unsafe decisions (Li et al., 2021). In the study by (Choi et al., 2019), they concluded that start-up time is shorter for older population, where they are less attentive and do not turn their head as frequent as younger population, thus; providing a less reliable vehicular travelling distance estimate.

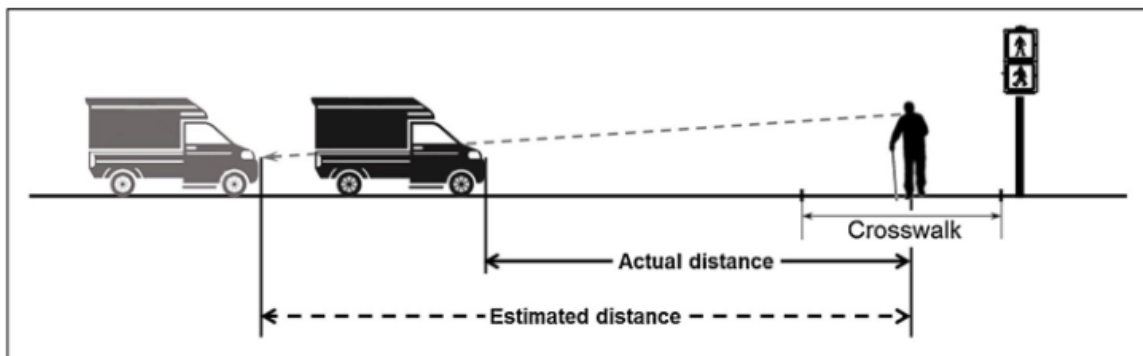


Figure 5: Estimated Distance from Approaching vehicle to Pedestrian. (Choi et al., 2019)

The figure above illustrates the approximate estimation from pedestrians to approaching vehicles at moment they feel it is unsafe to cross the road. Notably, the actual distance is perceived much closer, posing a significant safety risk. The study also provided recommendations on this topic, for instance, providing some sort of education programs and

training to enhance spatial and visual perception of older population by advising them to allow bigger gaps for crossing the road. Successful campaigns such as the Australian and British “Stop, Look, Listen” campaigns are cited as an effective solution alongside engineering solutions (Choi et al., 2019). Additionally, younger population are at risk when crossing without adults’ supervision, due to physical and cognitive reasons (Shorter height, running, poor attentional control and visual search). Alternatively, group of studies found that the presence of a female decreases the conflict between pedestrians and vehicles. The number of pedestrians crossing the street and taking evasive actions (gesturing at drivers) are positively attributing factor as well. In the YouTube video by Mark Rober, NICEST Car Horn Ever - DIY, he came up with a brilliant idea; installing the nicest car horn where he calls it the courtesy horn, his idea was to alert pedestrians and cars around him in a nicer way rather than the one-dimensional conventional horn. A common rule of thumb among drivers is to use the car horn in extreme cases, but what if you need to get someone’s attention in cases like forgetting an item on the top of the car’s roof or alerting the driver to a green light traffic signal, it can be seen as non-confrontational, this method can be seen as a way of drivers reacting with pedestrians and increasing road efficiency (Rober, 2017).

A reason of increasing pedestrian risk is distractions such as, texting, music, urban visual clutter, and phone usage. Lastly, speed change while using crosswalks would inflate pedestrian risk where acceptance of smaller gap is associated with higher speed, and critical gap was linked with higher risk (Li et al., 2021). Undoubtedly, when researchers attempted to capture the crossing behaviour at an intersection or pedestrians to understand the risk that they are subjected to, they found that the age and gender are very important factors in the process (Aziz et al., 2013).

2.3.2. Vehicular Characteristics:

Vehicular Characteristics play a role in moulding the safety dynamics at pedestrian crossings, the dance between the vehicles motion and pedestrian safety is essential to designing reliable roads and most importantly, safer pedestrian infrastructure. In this subsection, we look into the influencing factors for safety at a crosswalk, exploring the possible mitigation factors. Researchers identified the increase of driving speed is closely related to the increase of conflicts among pedestrians and vehicles, where it is only logical that such an increase would affect their safety. It is also suggested that pedestrians may have a higher risk when crossing paths with larger vehicles due to larger stop distances and heavier loads (Li et al., 2021).

2.3.3. Weather Conditions and Temporal Variation:

Weather Conditions and Temporal variations affect the pedestrian safety, where it is found that rainy and snowy weather conditions affect the visibility of pedestrians, and the probability of risky conflicts increase during afternoon and night (Li et al., 2021).

2.4. Intelligent Pedestrian Crossings and SafeXOne System:

Studies of pedestrian infrastructure enhancement aim to improve the safety of pedestrians, by utilizing innovative features and technologies. One of those pioneering technologies is the SafeXOne system, although it is not the only system that is available in the European market,

it is opposed to the conservative systems that call attention to pedestrian crossings presence, the system we aim to analyse its effects focuses directly on the pedestrian physical presence. The operational concept behind SafeXOne is based on alarms triggered by sensor signals. These sensors when triggered by a pedestrian walking through the designated area between two pillars, allow the system to flash a yellow hazard warning signal towards drivers approaching from both sides of the road. Moreover, the system is equipped with a homogenous laser plane over the surface of the road, which gives the pedestrian a dynamic movement nature for easily recognizable movement by drivers.

The necessity of such systems came from the increasing need to enhance safety, where the number of vehicle-pedestrian accidents is somehow declining, the cause remains important for governments and municipalities to take care of. Those accidents are typically caused by poor visibility at later times of the day, occlusion by road nature, distracted drivers, low visibility of pedestrians, and unsafe crossing approaches.

2.5.Gaps in Current Research:

Most of the previous studies focused on the safety of a particular intersection in regard to pedestrians, design, drivers' response to yielding, and surrounding elements as time of day. However, we aim to analyse the effect of speed profiles on one segment of the road, by studying two consecutive pedestrian crosswalks, and analysing the vehicular speed before and after installing the SafeXOne system. We noticed that the filling the void of this missing literature we could influence the way of thinking for decision makers and municipalities in Hungary making the streets safer to cross for young and elderly.

Chapter 3. Methodology:

3.1. Introduction:

In this chapter, we aim to provide a comprehensive overview of the methodology employed in this research, starting with the research design, data collection methods, data processing techniques, statistical analysis procedures, and ethical and limitations considerations of the study. The methodology is the benchmark that we chose to yield a successful study as it guides the systematic collection and analysis of data to address research objectives and answer the study's questions accurately.

3.2. Research Design:

In this section, we lay the groundwork for the research, aligning the framework on which we will build our theories. At the beginning of this thesis, we posed pivotal research questions, main being: "How does the installation of an Intelligent pedestrian crossing affect the speed profile of vehicles for a complete segment of the road?". To address this inquiry effectively, we are aware of the substantial importance of quantitative data and the accurate processing of them.

Data processing is necessary to filter out the speed profiles of vehicles approaching designated crosswalks along the identified road segment in Lövölde utca, Székesfehérvár. This filtering is done using algorithms to connect the timestamps of vehicles passing through each station of the SDR devices stationed at 10 meters intervals of the designated crosswalk, there are six devices from 0 meter to 50 meters.

Our approach requires a systematic analysis of numbers and speeds, primarily conducted through descriptive analysis done through excel software. This method allows us to focus on the key components such as average speeds, median values, and percentiles (specifically the 15th and 85th percentiles), fundamental for demonstrating the speed profiles of the approaching vehicles. Moreover, we intend to graphically represent the values enabling a comprehensive comparison of the whole segment of the road.

While our research design is robust and methodical, it is essential to acknowledge and address ethical and practical limitations encountered during the study. By defining these drawbacks, we ensure transparency in our research methodology, thus ensuring validity and reliability of our findings.

3.3. Data Collection Methods:

In this section, we describe the location of our study and elaborate our data collection methods. Firstly, the location of our survey is in Lövölde Street, Székesfehérvár, a 2*1 collector road located in the southern part of the city, close to the train station. The segment has three pedestrian crossings that serves the residents to commute safely within this mixed-use area, two of which are under study. This segment of the street has a speed limit of 50 km/hr, bus stations and sidewalks from each side, and a national bicycle lane on the further end, all shown in the figures below.

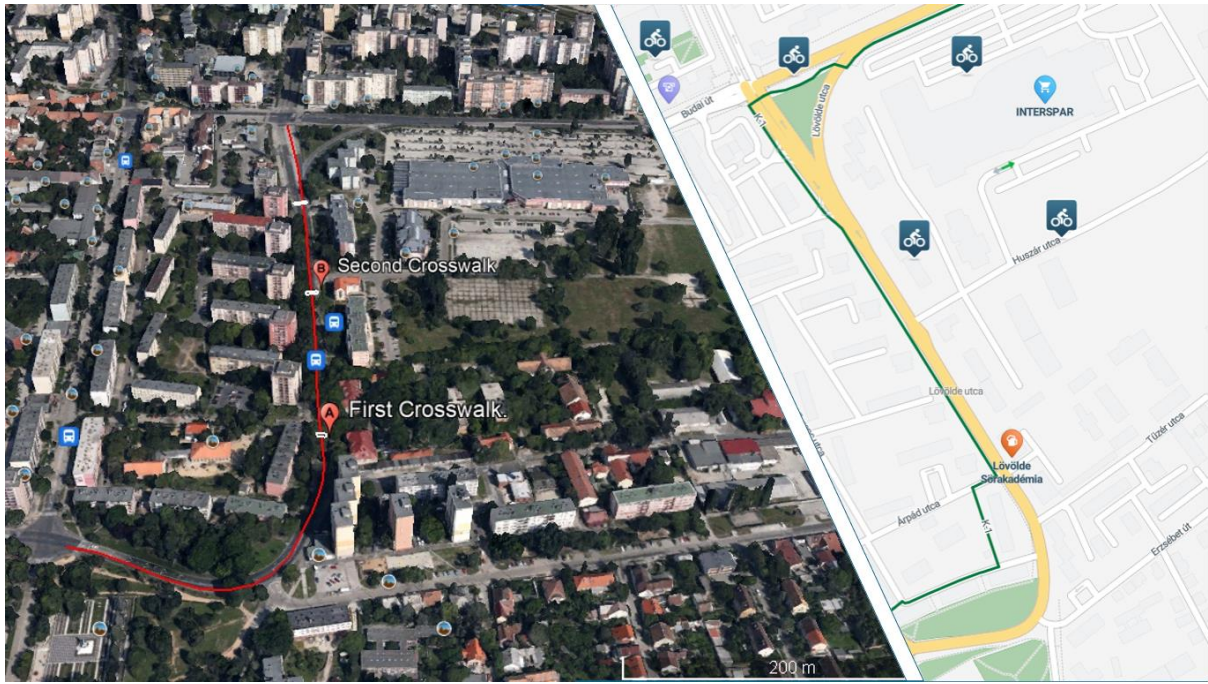


Figure 6: Aerial Location of the Study with Bike Lines and Crosswalks.

Our data collection methods which primarily revolves around collecting data utilizing SDR traffic classifier system. The SDR system is a non-intrusive tool, designed for acquiring measurement data, specifically for traffic surveys. One of the advantages of the SDR is the easy setup of the device, and the ability to monitor the data while on site using a smartphone.

Throughout the data collection process, we adhere to guidelines outlined in the SDR manual, which provides detailed instructions and visuals for efficient operation. This includes utilizing the SDR app for real-time monitoring and data retrieval. We initiate data collection by employing a logical systematic process of installing the SDR devices on 10 meters intervals, starting from zero distance, which is the pedestrian crossing, up to 50 meters away from the crosswalk on the oncoming lane traffic as shown in the figure below. This strategic placement ensures enhanced visibility and accuracy in speed measurement and safety of devices.



Figure 7: SDR Devices with Interval Distances.

These devices are mounted on tripods initially and then affixed to poles to elevate them for optimal data capture, the height of installation of at least 2.00 meters, and the measured distance between the devices and the middle of the oncoming lane differentiates from 5.00 meters to 8.00 meters to fit the properties of the site. The methodology of data collection is done using microwaves, capturing the velocity of the vehicle at a specific time stamp, then transferring the information to the memory. The device must be fixed with a 45 angle from the desired lane as shown in the figure below.

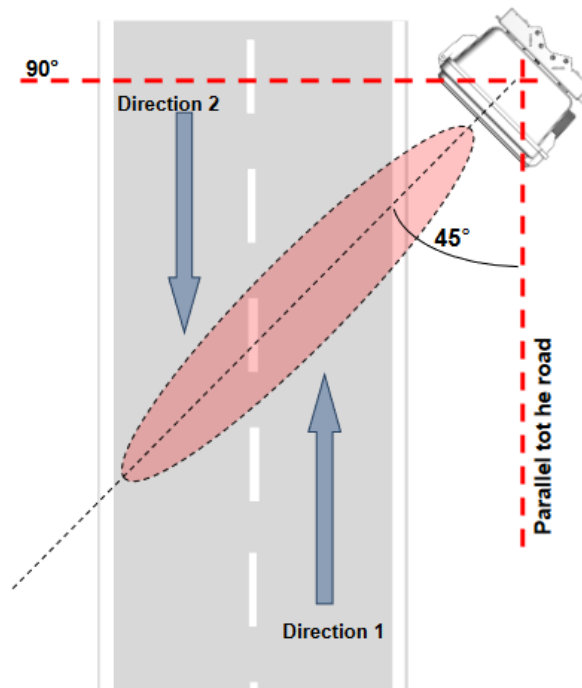


Figure 8: Methodology of SDR Device Speed Measurement.

We also utilized the feature of the SmartBracket, which is a mounting tool for the SDR devices on poles and trees shown in the figure below, this tool uses four locking bolts to fix the SmartBracket into the position, then the SDR case is hooked into place by a locking mechanism and secured by a padlock.



Figure 9: SmartBracket Mounting Mechanism with SDR Device.

After installing the devices, we connect the SDR to the power supply (12V battery installed within), then a registration process is commenced using a smartphone to connect the device to the cloud and phone using Bluetooth, the website used is www.myTrafficdata.com. Furthermore, we set the parameters of the SDR in the app, including distance from the street, height of installation, angle of the device, using the angle finder as shown in the figure below, and we start the data collection process, we made sure not to get double readings by correct

installation and observing the devices and the road for a period, double readings can be detected if they are given the same timestamp (SDR Manual, 2016).

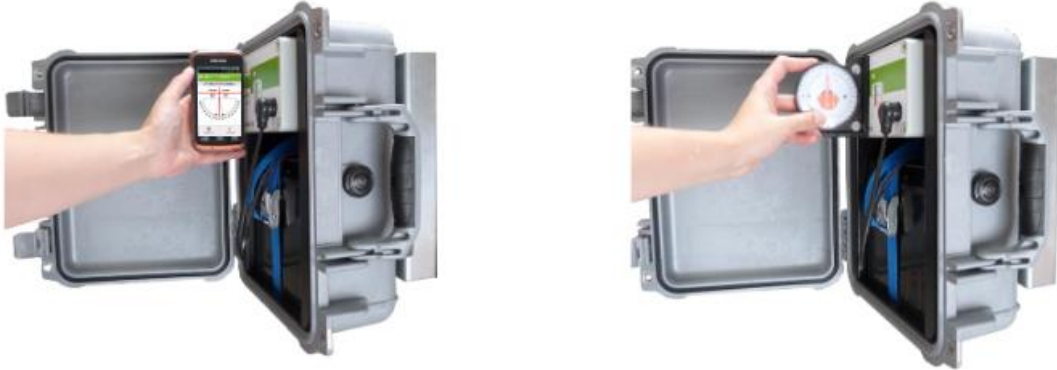


Figure 10: Angle Finder in Usage.

Additionally, we document the installation site before and after data collection, utilizing photographs to provide visual context and aid in data interpretation. In the figure below, we can see a comparison of the site before and after installing the SafeXOne intelligent system.



Figure 11: Before and After Photographs of the Study Location.

In the figure above, the left side shows the site before, the right side shows the site after installation, both photos were taken in March of 2024. By following these meticulous data collection procedures, we aimed to gather accurate and reliable data essential for our research objectives. Additionally, we remained mindful of ethical considerations, ensuring minimal disruption to traffic flow and respecting privacy regulations during the data collection process.

3.4. Data Processing Techniques:

In the data processing phase, we aim to refine the raw data collected during the traffic survey conducted on March 5th -6th, March 25th -26th to extract insights into the traffic behaviour and vehicle speed profiles. The data collection involves measuring speeds of vehicles passing through SDR devices at a specific timestamp, thus providing a speed profile for vehicles preceding two pedestrian crossings.

To analyse the raw data effectively, it is extracted from the SDR devices in SmartDraw format (.sdr) after connecting them to a smartphone via Bluetooth. This data is transferred to a computer, where the files are converted to Excel format (.xlsx) using the website provided by the devices (www.Mytrafficdata.com). This conversion enables handling and analysis of the data as the files cannot be opened without this conversion.

Once in Excel format, the data is uploaded into separate sheets. Where it undergoes filtering and refinement to enhance accuracy. Duplicate readings, if any, are identified and removed using Excel's built-in functions, ensuring that each data point is unique and representative. Initially, we had an extra column of vehicle length, but after observing inconsistencies between devices we decided to disregard the data and focus on the core data points.

We then paired timestamps with corresponding speeds as shown in the table below to produce a single speed profile for a vehicle, this was the first reading for our data set of the data acquired in the after installation of the first crossing. We can notice that the vehicle approached with a 42 km/h speed and ended up with a 37 km/h, by using the velocity equation: $v = d/t$, where v =velocity (km/h converted to m/s), d = displacement (m) and t =time (s). Our displacement is fixed between devices, previously mentioned as 10 m, and velocity is provided through SDR, such application can be used to predict the timing of the same vehicle for the following crossing, although this application remains a consideration for future use.

Table 1: Speed Profile Example.

SDR: A_16		SDR: A_15		SDR: A_14		SDR: A_13		SDR: A_12		SDR: A_11	
TimeStamp	Speed	TimeStamp	Speed	TimeStamp	Speed	TimeStamp	Speed	TimeStamp	Speed	TimeStamp	Speed
19:00:04	42 km/h	19:00:05	43 km/h	19:00:06	36 km/h	19:00:08	41 km/h	19:00:09	40 km/h	19:00:10	37 km/h

3.5. Statistical Analysis Procedures:

In this section, we explore data analysis methods used to examine the speed profiles of vehicles approaching pedestrian crossings in our study. As part of our research methodology, we employed a systematic approach to analyse the collected data, aiming to come up with meaningful results of safety outcomes. Utilizing Excel software as our primary tool, we conducted descriptive analysis and calculated key statistical data to characterize the speed profiles of vehicles.

These measures of descriptive analysis included but not limited to, Mean, Median, Mode, Minimum, Maximum, Sum, and Count, they provided a clear perspective on central tendency, variability, and distribution of vehicles speeds. Moreover, we computed percentiles of V85, V50, and V15 to identify critical threshold for traffic safety and to determine if changes are needed. This data analysis process is needed to draw conclusions regarding the safety of pedestrian crossings after installing the SafeXOne system. The use of traffic dynamics and statistical methods simplified the raw data we have into a much understandable informing evidence-based decisions for road safety authorization.

3.6. Research Limitations and Ethical Considerations:

In this section, we address both the ethical considerations and research limitations that we encountered during our study conducted in Székesfehérvár. Firstly, we acknowledge certain limitations inherent in our study, these limitations include the concern of safety for our devices, where the SDR devices are not cheap and when mounted on a tripod and a pole they can be stolen easily, thus; we had to observe the devices through out the night to ensure that the devices will not be stolen or tampered with. Additionally, the location of the study is 85 km away from Gyor, so we were unable to conduct the data collection for more than 24 hours.

Regarding ethical considerations, we took proactive measures to ensure the privacy and confidentiality of the data collected. While we aimed to capture data on vehicle speeding behaviours, we paid attention to safeguarding individual privacy and refrained from collecting identifiable information on vehicles exceeding speed limits. Moreover, we prioritized non-intrusive data collection methods to minimize disruption to traffic flow and maintain the integrity of our dataset, such as covering the poles with duct tape to make it easier to blend with the location and not interrupt the flow of vehicles as shown in the figure below.



Figure 12: SDR Mounting Poles Before and After Covering.

Despite these limitations and ethical considerations, we maintained a honest data analysis methodology. However, it is important to acknowledge the potential impact of these limitations on the validity and reliability of our findings. We recognize that our analysis may be influenced by inherent biases or errors in the data, and we urge careful interpretation of statistical measures within the context of traffic safety. By transparently addressing these limitations and ethical considerations, we uphold the integrity of our research and provide valuable vision for future studies in this field.

Chapter 4. Data Collection:

In this section, we present an overview of the data collected from traditional pedestrian crossings utilizing SDR devices, as mentioned before. The data collection process occurred over a period of 24 hours, specifically from 19:00:00 on the 5th of March to 19:00:00 on the 6th of March, and from 19:00:00 on the 25th of March to 19:00:00 on the 26th of March.

The data collection involved multiple SDR devices strategically positioned at designated locations along the traditional pedestrian crossings before and after installation of the SafeXOne system. Each device recorded data at a frequency of one data point per second, capturing essential metrics such as vehicle speed. Weather conditions during the data collection period were clear, ensuring consistency in data quality.

Overall, the dataset contains more than 6000 readings for each device, resulting in a extensive collection of data points for analysis. To provide a glimpse of the dataset, we include a sample of tables below, showing the key factors of timestamps and vehicles speed. Additionally, a preliminary speed profile analysis is conducted to offer initial insights into the vehicular behaviour near traditional pedestrian and smart pedestrian crossings, the word “correct” shows that the timings lineup for the speed profile showing the speed of single vehicle.

Table 2: Before Installation Raw Data, Pedestrian Crossing 1.

Before Installation, Pedestrian Crossing 1												
6		5		4		3		2		1		Speed Profile
Time	Speed	Time	Speed	Time	Speed	Time	Speed	Time	Speed	Time	Speed	
19:00:05	45 km/h	19:00:06	41 km/h	19:00:07	48 km/h	19:00:07	47 km/h	19:00:09	50 km/h	19:00:10	46 km/h	Correct
19:00:22	44 km/h	19:00:24	44 km/h	19:00:25	44 km/h	19:00:25	45 km/h	19:00:27	44 km/h	19:00:27	41 km/h	Correct
19:00:25	46 km/h	19:00:27	46 km/h	19:00:27	45 km/h	19:00:28	46 km/h	19:00:30	46 km/h	19:00:30	44 km/h	Correct
19:01:18	42 km/h	19:01:19	41 km/h	19:01:20	39 km/h	19:01:21	37 km/h	19:01:23	39 km/h	19:01:24	40 km/h	Correct
19:01:20	47 km/h	19:01:21	47 km/h	19:01:22	47 km/h	19:01:22	47 km/h	19:01:24	44 km/h	19:01:25	41 km/h	Correct
19:01:21	47 km/h	19:01:23	45 km/h	19:01:23	45 km/h	19:01:24	47 km/h	19:01:26	46 km/h	19:01:26	45 km/h	Correct
19:01:24	48 km/h	19:01:26	46 km/h	19:01:27	46 km/h	19:01:27	46 km/h	19:01:29	46 km/h	19:01:30	44 km/h	Correct
19:01:29	47 km/h	19:01:31	49 km/h	19:01:31	49 km/h	19:01:32	51 km/h	19:01:34	49 km/h	19:01:34	48 km/h	Correct
19:01:51	49 km/h	19:01:52	49 km/h	19:01:53	50 km/h	19:01:53	50 km/h	19:01:54	49 km/h	19:01:55	49 km/h	Correct
19:02:18	67 km/h	19:02:19	65 km/h	19:02:20	67 km/h	19:02:19	64 km/h	19:02:21	59 km/h	19:02:22	54 km/h	False
19:02:35	50 km/h	19:02:37	45 km/h	19:02:37	53 km/h	19:02:37	54 km/h	19:02:39	55 km/h	19:02:39	55 km/h	Correct
19:03:13	45 km/h	19:03:15	40 km/h	19:03:16	44 km/h	19:03:16	44 km/h	19:03:18	43 km/h	19:03:18	41 km/h	Correct
19:03:18	44 km/h	19:03:20	41 km/h	19:03:21	43 km/h	19:03:21	44 km/h	19:03:23	43 km/h	19:03:24	38 km/h	Correct
19:03:25	39 km/h	19:03:27	37 km/h	19:03:28	39 km/h	19:03:28	39 km/h	19:03:31	35 km/h	19:03:32	34 km/h	Correct
19:03:27	40 km/h	19:03:29	39 km/h	19:03:30	40 km/h	19:03:30	40 km/h	19:03:32	39 km/h	19:03:33	37 km/h	Correct
19:03:31	41 km/h	19:03:33	39 km/h	19:03:34	41 km/h	19:03:35	44 km/h	19:03:37	43 km/h	19:03:37	42 km/h	Correct
19:03:42	46 km/h	19:03:44	47 km/h	19:03:44	44 km/h	19:03:45	45 km/h	19:03:47	44 km/h	19:03:48	42 km/h	Correct
19:03:46	51 km/h	19:03:47	47 km/h	19:03:48	47 km/h	19:03:48	45 km/h	19:03:50	46 km/h	19:03:51	41 km/h	Correct

Table 3: Before Installation Raw Data, Pedestrian Crossing 2.

Before Installation, Pedestrian Crossing 2											
6		5		4		3		2		1	
Time	Speed	Time	Speed	Time	Speed	Time	Speed	Time	Speed	Time	Speed
19:00:18	45 km/h	19:00:19	46 km/h	19:00:20	41 km/h	19:00:21	53 km/h	19:00:22	49 km/h	19:00:23	48 km/h
19:00:36	42 km/h	19:00:39	42 km/h	19:00:39	38 km/h	19:00:40	49 km/h	19:00:40	45 km/h	19:00:42	44 km/h
19:00:39	46 km/h	19:00:41	45 km/h	19:00:41	36 km/h	19:00:42	50 km/h	19:00:43	46 km/h	19:00:45	47 km/h
19:01:31	49 km/h	19:01:33	48 km/h	19:01:34	38 km/h	19:01:34	52 km/h	19:01:35	47 km/h	19:01:37	47 km/h
19:01:34	50 km/h	19:01:35	50 km/h	19:01:35	43 km/h	19:01:36	54 km/h	19:01:37	49 km/h	19:01:38	48 km/h
19:01:35	48 km/h	19:01:37	48 km/h	19:01:37	42 km/h	19:01:38	53 km/h	19:01:39	52 km/h	19:01:41	49 km/h
19:01:39	46 km/h	19:01:40	48 km/h	19:01:41	43 km/h	19:01:41	54 km/h	19:01:42	50 km/h	19:01:43	48 km/h
19:01:43	44 km/h	19:01:45	44 km/h	19:01:45	38 km/h	19:01:46	50 km/h	19:01:46	45 km/h	19:01:48	45 km/h
19:02:04	51 km/h	19:02:05	48 km/h	19:02:06	40 km/h	19:02:06	54 km/h	19:02:07	51 km/h	19:02:09	46 km/h
19:02:30	43 km/h	19:02:05	45 km/h	19:02:32	36 km/h	19:02:33	49 km/h	19:02:34	44 km/h	19:02:35	46 km/h
19:02:46	53 km/h	19:02:31	43 km/h	19:02:48	48 km/h	19:02:49	58 km/h	19:02:50	57 km/h	19:02:51	53 km/h
19:03:13	47 km/h	19:02:48	53 km/h	19:03:15	43 km/h	19:03:15	57 km/h	19:03:17	51 km/h	19:03:18	48 km/h
19:03:29	37 km/h	19:03:14	49 km/h	19:03:31	31 km/h	19:03:32	43 km/h	19:03:33	37 km/h	19:03:35	36 km/h
19:03:35	38 km/h	19:03:30	38 km/h	19:03:37	32 km/h	19:03:37	44 km/h	19:03:39	41 km/h	19:03:41	41 km/h
19:03:42	38 km/h	19:03:36	38 km/h	19:03:45	32 km/h	19:03:46	40 km/h	19:03:47	34 km/h	19:03:49	31 km/h
19:03:44	37 km/h	19:03:44	39 km/h	19:03:47	32 km/h	19:03:48	39 km/h	19:03:49	31 km/h	19:03:52	22 km/h
19:03:48	33 km/h	19:03:46	38 km/h	19:03:52	25 km/h	19:03:52	35 km/h	19:03:54	33 km/h	19:03:56	36 km/h
19:03:53	41 km/h	19:03:50	31 km/h	19:03:56	40 km/h	19:03:56	52 km/h	19:03:57	48 km/h	19:03:59	44 km/h
19:03:58	37 km/h	19:03:55	43 km/h	19:04:00	34 km/h	19:04:01	43 km/h	19:04:02	40 km/h	19:04:04	38 km/h

Table 4: After Installation Raw Data, Pedestrian Crossing 1.

After Installation, Pedestrian Crossing 1											
6		5		4		3		2		1	
Time	Speed	Time	Speed	Time	Speed	Time	Speed	Time	Speed	Time	Speed
19:00:04	42 km/h	19:00:05	43 km/h	19:00:06	36 km/h	19:00:08	41 km/h	19:00:09	40 km/h	19:00:10	37 km/h
19:00:07	41 km/h	19:00:06	42 km/h	19:00:08	37 km/h	19:00:10	37 km/h	19:00:11	40 km/h	19:00:12	38 km/h
19:00:09	42 km/h	19:00:09	42 km/h	19:00:11	36 km/h	19:00:13	39 km/h	19:00:14	43 km/h	19:00:32	43 km/h
19:00:27	53 km/h	19:00:28	54 km/h	19:00:29	45 km/h	19:00:30	48 km/h	19:00:32	49 km/h	19:00:37	42 km/h
19:00:32	44 km/h	19:00:33	45 km/h	19:00:34	41 km/h	19:00:36	42 km/h	19:00:37	43 km/h	19:00:54	46 km/h
19:00:50	60 km/h	19:00:50	60 km/h	19:01:13	45 km/h	19:00:52	54 km/h	19:00:54	53 km/h	19:01:17	45 km/h
19:01:12	54 km/h	19:01:12	53 km/h	19:01:35	40 km/h	19:01:15	46 km/h	19:01:16	46 km/h	19:01:38	41 km/h
19:01:33	43 km/h	19:01:34	44 km/h	19:01:37	40 km/h	19:01:37	39 km/h	19:01:38	40 km/h	19:01:40	38 km/h
19:01:35	44 km/h	19:01:35	44 km/h	19:01:38	39 km/h	19:01:38	40 km/h	19:01:40	41 km/h	19:01:42	40 km/h
19:01:37	43 km/h	19:01:37	43 km/h	19:01:39	38 km/h	19:01:40	41 km/h	19:01:41	41 km/h	19:01:43	37 km/h
19:01:38	46 km/h	19:01:38	43 km/h	19:01:52	59 km/h	19:01:41	40 km/h	19:01:42	40 km/h	19:02:32	42 km/h
19:01:52	67 km/h	19:01:51	65 km/h	19:02:28	45 km/h	19:01:54	60 km/h	19:01:55	59 km/h	19:03:43	48 km/h
19:02:27	54 km/h	19:02:27	54 km/h	19:03:07	50 km/h	19:02:30	44 km/h	19:02:31	45 km/h	19:04:37	50 km/h
19:03:06	54 km/h	19:03:06	55 km/h	19:03:09	49 km/h	19:03:08	52 km/h	19:03:10	53 km/h	19:04:42	45 km/h
19:03:08	56 km/h	19:03:08	57 km/h	19:03:39	45 km/h	19:03:11	50 km/h	19:03:12	52 km/h	19:05:04	39 km/h
19:03:38	49 km/h	19:03:39	50 km/h	19:04:34	51 km/h	19:03:41	47 km/h	19:03:42	51 km/h	19:05:06	44 km/h
19:04:33	53 km/h	19:04:33	56 km/h	19:04:39	42 km/h	19:04:35	48 km/h	19:04:37	53 km/h	19:05:34	48 km/h
19:04:38	48 km/h	19:04:38	50 km/h	19:05:00	43 km/h	19:04:41	46 km/h	19:04:42	49 km/h	19:05:45	63 km/h
19:04:59	49 km/h	19:04:59	49 km/h	19:05:03	43 km/h	19:05:02	45 km/h	19:05:04	45 km/h	19:05:58	52 km/h
19:05:01	48 km/h	19:05:02	47 km/h	19:05:30	45 km/h	19:05:05	44 km/h	19:05:06	46 km/h	19:06:05	37 km/h

Table 5: After Installation Raw Data, Pedestrian Crossing 1.

After Installation, Pedestrian Crossing 2												
6		5		4		3		2		1		Speed Profile
Time	Speed	Time	Speed	Time	Speed	Time	Speed	Time	Speed	Time	Speed	
19:00:03	45 km/h	19:00:05	46 km/h	19:00:05	44 km/h	19:00:07	45 km/h	19:00:07	43 km/h	19:00:09	43 km/h	Correct
19:00:09	40 km/h	19:00:11	40 km/h	19:00:11	35 km/h	19:00:13	39 km/h	19:00:14	36 km/h	19:00:15	41 km/h	Correct
19:00:21	34 km/h	19:00:23	32 km/h	19:00:24	29 km/h	19:00:26	30 km/h	19:00:27	24 km/h	19:00:30	19 km/h	Correct
19:00:23	31 km/h	19:00:25	28 km/h	19:00:26	27 km/h	19:00:31	28 km/h	19:00:30	22 km/h	19:00:33	20 km/h	False
19:00:26	30 km/h	19:00:28	27 km/h	19:00:29	24 km/h	19:00:44	50 km/h	19:00:32	20 km/h	19:00:35	21 km/h	False
19:00:40	49 km/h	19:00:42	48 km/h	19:00:43	45 km/h	19:00:49	52 km/h	19:00:44	45 km/h	19:00:46	49 km/h	False
19:00:46	51 km/h	19:00:47	49 km/h	19:00:48	48 km/h	19:01:05	50 km/h	19:00:50	48 km/h	19:00:51	50 km/h	False
19:01:01	52 km/h	19:01:03	51 km/h	19:01:03	46 km/h	19:01:28	41 km/h	19:01:06	35 km/h	19:01:08	25 km/h	False
19:01:24	47 km/h	19:01:26	43 km/h	19:01:27	38 km/h	19:01:53	40 km/h	19:01:29	37 km/h	19:01:31	10 km/h	False
19:01:48	39 km/h	19:01:50	35 km/h	19:01:51	35 km/h	19:01:54	42 km/h	19:01:53	36 km/h	19:01:55	39 km/h	False
19:01:50	36 km/h	19:01:52	37 km/h	19:01:52	35 km/h	19:01:58	40 km/h	19:01:55	36 km/h	19:01:57	40 km/h	False
19:01:51	36 km/h	19:01:54	34 km/h	19:01:54	35 km/h	19:02:05	52 km/h	19:01:56	39 km/h	19:01:58	42 km/h	False
19:01:53	36 km/h	19:01:55	34 km/h	19:01:56	33 km/h	19:02:43	51 km/h	19:01:58	39 km/h	19:02:00	46 km/h	False
19:02:01	60 km/h	19:02:03	57 km/h	19:02:03	55 km/h	19:03:22	48 km/h	19:02:06	45 km/h	19:02:07	50 km/h	False
19:02:39	52 km/h	19:02:41	50 km/h	19:02:41	45 km/h	19:03:25	41 km/h	19:02:44	47 km/h	19:02:45	52 km/h	False
19:03:18	49 km/h	19:03:19	49 km/h	19:03:20	46 km/h	19:03:55	45 km/h	19:03:22	41 km/h	19:03:24	46 km/h	False
19:03:21	41 km/h	19:03:23	40 km/h	19:03:23	37 km/h	19:04:49	47 km/h	19:03:26	37 km/h	19:03:27	40 km/h	False
19:03:51	39 km/h	19:03:53	39 km/h	19:03:53	39 km/h	19:04:56	45 km/h	19:03:56	43 km/h	19:03:46	12 km/h	False
19:04:45	47 km/h	19:04:47	46 km/h	19:04:47	44 km/h	19:05:18	38 km/h	19:04:49	42 km/h	19:03:57	45 km/h	False
19:04:52	42 km/h	19:04:53	41 km/h	19:04:54	39 km/h	19:05:20	33 km/h	19:04:56	42 km/h	19:04:51	46 km/h	False

In the tables above, a sample of data is provided for the two pedestrian crossings before and after the installation of the SafeXOne system, where it might be hard to process such information at once, but the logical flow is understandable.

Chapter 5. Data Analysis and Results:

In this chapter we present a comparative analysis between the speed profiles of vehicles approaching traditional pedestrian crossings and those approaching SafeXOne pedestrian crossings. The primary focus of this comparison is on the V85 percentile speed, which represents the speed at or below which 85% of vehicles are traveling. By examining the V85 values for both types of crossings, we aim to assess the effectiveness of the SafeXOne system in reducing vehicle speeds and improving pedestrian safety. Additionally, we will analyse other key statistical measures such as the mean and median to provide a comprehensive understanding of the differences between the two types of crossings. Through this comparative analysis, we seek to identify any significant differences in vehicle speeds and safety outcomes between traditional and SafeXOne pedestrian crossings. In the tables below, we have the descriptive statistics values between before and after installation of the SafeXOne pedestrian system.

Table 6: Statistical Analysis of Before Installation Crossing 1.

Before Installation, Crossing number 1						
Statistical Factor	Device Distance from Crossing					
	50 m	40 m	30 m	20 m	10 m	0 m
Mean	43.80324038	42.16938	42.42591	42.36988	41.92328	39.8904
Standard Error	0.093228935	0.106651	0.109434	0.121921	0.121377	0.117304
Median	44	43	43	44	44	42
Mode	45	46	46	46	44	44
Standard Deviation	7.469377524	8.649249	8.785462	9.825049	9.759325	9.553586
Sample Variance	55.79160059	74.80951	77.18434	96.53158	95.24442	91.27101
Kurtosis	3.355243052	2.596854	1.307497	1.246903	1.377406	1.053736
Skewness	-0.975700728	-1.08086	-0.69568	-0.92089	-0.9691	-0.85286
Range	67	68	73	73	77	72
Minimum	7	5	7	6	6	6
Maximum	74	73	80	79	83	78
Sum	281173	277348	273435	275150	271034	264593
Count	6419	6577	6445	6494	6465	6633
V85	50	49	50	51	50	48
V50	44	43	43	44	44	42
V15	38	35	35	33	33	30

Table 7: Statistical Analysis of Before Installation Crossing 2.

Before Installation, Crossing number 2						
Statistical Factor	Device Distance from Crossing					
	50 m	40 m	30 m	20 m	10 m	0 m
Mean	43.80324038	42.16938	42.42591	42.36988	41.92328	39.8904
Standard Error	0.093228935	0.106651	0.109434	0.121921	0.121377	0.117304
Median	44	43	43	44	44	42
Mode	45	46	46	46	44	44
Standard Deviation	7.469377524	8.649249	8.785462	9.825049	9.759325	9.553586
Sample Variance	55.79160059	74.80951	77.18434	96.53158	95.24442	91.27101
Kurtosis	3.355243052	2.596854	1.307497	1.246903	1.377406	1.053736
Skewness	-0.975700728	-1.08086	-0.69568	-0.92089	-0.9691	-0.85286
Range	67	68	73	73	77	72
Minimum	7	5	7	6	6	6
Maximum	74	73	80	79	83	78
Sum	281173	277348	273435	275150	271034	264593
Count	6419	6577	6445	6494	6465	6633
V85	50	49	50	51	50	48
V50	44	43	43	44	44	42
V15	38	35	35	33	33	30

Table 8: Statistical Analysis of After Installation Crossing 1.

After Installation, Crossing number 1						
Statistical Factor	Device Distance from Crossing					
	50 m	40 m	30 m	20 m	10 m	0 m
Mean	46.59253776	47.18223	39.56539	40.71482	41.92695	39.40394
Standard Error	0.102528349	0.10108	0.110031	0.122013	0.129653	0.118574
Median	48	48	41	43	44	41
Mode	48	47	40	45	44	44
Standard Deviation	8.426058949	8.095874	9.178236	10.16666	10.76898	9.928389
Sample Variance	70.99846941	65.54318	84.24001	103.3609	115.9709	98.5729
Kurtosis	3.41615486	2.364082	1.025583	0.846997	0.958625	0.703784
Skewness	-1.132992397	-0.62435	-0.68406	-0.77632	-0.86131	-0.68946
Range	87	97	89	95	99	96
Minimum	9	7	5	7	6	6
Maximum	96	104	94	102	105	102
Sum	314686	302674	275296	282683	289254	276261
Count	6754	6415	6958	6943	6899	7011
V85	54	54	48	50	51	48
V50	48	48	41	43	44	41
V15	40	40	30	30	30	28

Table 9: Statistical Analysis of After Installation Crossing 2.

After Installation, Crossing number 2						
Statistical Factor	Device Distance from Crossing					
	50 m	40 m	30 m	20 m	10 m	0 m
Mean	39.97159168	38.39119	35.67366	39.36331	35.59578	37.67102
Standard Error	0.097134771	0.103745	0.104343	0.114576	0.117542	0.127531
Median	41	39	37	41	37	40
Mode	42	38	37	44	40	45
Standard Deviation	8.331536478	8.895476	8.942466	9.763157	9.914701	10.98766
Sample Variance	69.41450009	79.1295	79.9677	95.31923	98.3013	120.7287
Kurtosis	1.91615135	1.254597	0.729237	0.403171	0.185244	-0.30277
Skewness	-0.697588418	-0.62661	-0.59438	-0.51497	-0.41609	-0.39469
Range	91	88	84	91	90	82
Minimum	8	6	6	9	5	8
Maximum	99	94	90	100	95	90
Sum	294071	282252	262023	285817	253264	279632
Count	7357	7352	7345	7261	7115	7423
V85	48	46	44	48	45	48
V50	41	39	37	41	37	40
V15	33	30	26	29	25	25

Upon reviewing the data presented in the tables above, several observations come to light. For instance, we noted that the V85 values for the first crossing remained stable on average before and after installation. This consistency can be attributed to the fact that it may take some time for drivers to fully adjust to the new road conditions. Furthermore, there was a

slight increase in the mode and median values for the first crossing post-installation. Conversely, we observed a notable decrease in the V85 values for the second crossing before and after installation, indicating an improvement in pedestrian safety. This decrease in the speeds of 85% of drivers contributes to a safer pedestrian crossing environment. Additionally, there was a decrease in the mode and median values for the second crossing post-installation, further validating our hypothesis that implementing a smart pedestrian crossing would result in a safer road segment.

Chapter 6. Conclusion and Recommendations:

In conclusion, this research has provided remarkable insights into the effectiveness of intelligent pedestrian crossings in enhancing road safety and reducing vehicle speeds. Through an analysis of data collected from both traditional and SafeXOne pedestrian crossings, we have demonstrated the potential of innovative technologies to significantly improve pedestrian safety outcomes.

The comparative analysis revealed notable differences in vehicle speeds before and after the installation of the SafeXOne system, particularly in the V85 percentile speeds. While the first crossing showed minimal changes, the second crossing exhibited a significant decrease in V85 values post-installation, indicating a safer pedestrian environment.

These findings underscore the importance of smart infrastructure solutions in modern urban environments, where pedestrian safety is an utmost concern. By leveraging technology to optimize traffic flow and enhance pedestrian crossings, cities can create safer and more accessible spaces for residents and visitors alike.

Moving forward, it is imperative for policymakers, urban planners, and transportation authorities to prioritize the implementation of intelligent pedestrian crossings as part of road safety strategies. Moreover, continued research and innovation in this area are essential to further refine and optimize smart infrastructure solutions for maximum effectiveness.

In conclusion, this study underscores the transformative potential of intelligent pedestrian crossings in fostering safer and more sustainable urban environments. By embracing innovative technologies and evidence-based approaches, we can strive towards a future where pedestrian safety is prioritized and road accidents are minimized.

To enhance pedestrian safety and promote healthy urban mobility, it is recommended to prioritize the expansion of intelligent pedestrian crossings, such as the SafeXOne system, in high-traffic areas with a history of safety concerns.

Continuous monitoring and evaluation of these crossings are essential to assess their effectiveness and identify areas for improvement. Public awareness campaigns should be launched to educate pedestrians, cyclists, and motorists about safe crossing practices and the benefits of intelligent pedestrian crossings. Collaboration among stakeholders and investment in research and development especially persons in charge are crucial to drive innovation and address complex urban mobility challenges. Supportive policies and regulations should be implemented to help the adoption of intelligent pedestrian crossings and ensure compliance with safety standards. By implementing these recommendations, cities can create safer, more accessible, and sustainable environments for all road users.

Chapter 7. References:

- Amundsen, F. and Hydén, C., 1977. First workshop on traffic conflicts. Institute of Transportation Economics. Lund, Sweden: Lund Institute of Technology.
- Hydén, C., 1987. The development of a method for traffic safety evaluation: The Swedish Traffic Conflicts Technique. Bulletin Lund Institute of Technology, Department, (70).
- Aziz, H.M.A., Ukkusuri, S.V., Hasan, S., 2013. Exploring the determinants of pedestrian–vehicle crash severity in New York City. *Accid. Anal. Prev.* 50, 1298–1309. <https://doi.org/10.1016/j.aap.2012.09.034>
- Choi, J., Tay, R., Kim, S., Jeong, S., 2019. Behaviors of older pedestrians at crosswalks in South Korea. *Accid. Anal. Prev.* 127, 231–235. <https://doi.org/10.1016/j.aap.2019.03.005>
- Costa, M., Lantieri, C., Vignali, V., Ghasemi, N., Simone, A., 2020. Evaluation of an integrated lighting-warning system on motorists' yielding at unsignalized crosswalks during nighttime. *Transp. Res. Part F Traffic Psychol. Behav.* 68, 132–143. <https://doi.org/10.1016/j.trf.2019.12.004>
- Hussain, Q., Alhajyaseen, W.K.M., Kharbeche, M., Almallah, M., 2023. Safer pedestrian crossing facilities on low-speed roads: Comparison of innovative treatments. *Accid. Anal. Prev.* 180, 106908. <https://doi.org/10.1016/j.aap.2022.106908>
- Iasmin, H., Kojima, A., Kubota, H., 2016. Safety effectiveness of pavement design treatment at intersections: Left turning vehicles and pedestrians on crosswalks. *IATSS Res.* 40, 47–55. <https://doi.org/10.1016/j.iatssr.2016.04.001>
- Li, H., Zhang, Z., Sze, N.N., Hu, H., Ding, H., 2021. Safety effects of law enforcement cameras at non-signalized crosswalks: A case study in China. *Accid. Anal. Prev.* 156, 106124. <https://doi.org/10.1016/j.aap.2021.106124>
- Mark Rober. (2017, June 14). *NICEST Car Horn Ever- DIY* [Video]. YouTube. https://www.youtube.com/watch?v=lv8wqnk_TsA
- Pedestrian Refuge Island Safe Transportation for Every Pedestrian Countermeasure Tech Sheet, n.d.
- Perkins, S.R., n.d. Traffic conflict characteristics-accident potential at intersections.
- Pogatsnik, M., Fischer, D., Nagy, L., Dora, S., 2020. Autonomous pedestrian crossing in smart city environment, in: 2020 IEEE 24th International Conference on Intelligent Engineering Systems (INES). Presented at the 2020 IEEE 24th International Conference on Intelligent Engineering Systems (INES), IEEE, Reykjavík, Iceland, pp. 37–42. <https://doi.org/10.1109/INES49302.2020.9147188>
- SDR Manual, 2016.pdf, 2016.
- Svensson, Å., n.d. A method for analysing the traffic process in a safety perspective.
- Regulation of pedestrian priority at pedestrian crossings in the Vienna Convention* / (2002) United Nations. Available at: <https://digitallibrary.un.org/record/458014?ln=en#record-files-collapse-header> (Accessed: 22 February 2024).

Li, H., Zhang, Z., Sze, N.N., Hu, H. and Ding, H., 2021. Safety effects of law enforcement cameras at non-signalized crosswalks: A case study in China. *Accident Analysis & Prevention*, 156, p.106124.