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DEVELOPMENT OF THE METHODOLOGY FOR SELECTING THE OPTIMAL TYPE OF PEDESTRIAN CROSSING

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Abstract: *The World Health Organization in its agenda on sustainable development 2030 sets a goal to reduce the number of traffic-related accidents by 50%. According to the trend toward reducing the number of traffic-related accidents and the latest statistics report by SIA Bitola, we have found that this is a great challenge for our city and a very high goal which we could try to reach. Namely, we have started a pedestrian safety initiative by trying to provide infrastructural facilities and elements that are planned and designed according to the security principles and which correspond to the projected speed and road function as well as safe infrastructure for pedestrians, the elderly and persons with disabilities. The main objective of this paper is to develop a case study methodology regarding the selection of pedestrian crossing types on the case study location example. Namely, the VISSIM simulation model for the studied location has been introduced, and the general conclusions have been adopted based on the multi-criteria decision-making process analysis. The most important aim is directed towards obtaining pedestrian safety while bearing in mind the role of pedestrian safety within the current safety goals.*

Key Words: *Pedestrian Safety; Pedestrian Crossing, AHP, VISSIM Simulation*

1. Introduction

Pedestrians are the most vulnerable road users. In many countries, collisions with pedestrians are a leading cause of death and injury, and over half of all road deaths are caused by collisions between vehicles and pedestrians that occur in a number of situations, especially including walking while trying to cross the road. The process of pedestrian traffic is influenced by a number of factors, of which the urban

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environment and streetscape are very important (AASHTO, 2010, 2014). The severity of pedestrian crashes is strongly dependent on traffic speed whereas the risk of pedestrian injuries is increased by a number of factors related to the road environment, including high traffic speed, inadequate crossing facilities, lack of pedestrian crossing opportunities (gaps in passing traffic), number of lanes to cross, complexity and unpredictability of traffic movements, inadequate separation from traffic and poor crossing sight distance as well. In OECD countries, traffic accidents cause 41% of fatalities among 14-year-olds. In Spain, nine children aged between 6 and 14 died from a traffic-related accident while five of them were pedestrians (Road Safety Inspection Manual for School Zones, 2014). Moreover, according to Principle 2 of the Declaration of the Rights of the Child, "The child shall enjoy special protection, and shall be given opportunities and facilities, by law and by other means, to enable him/her to develop physically, mentally, morally, spiritually and socially in a healthy and normal manner and in conditions of freedom and dignity"(Geneva Declaration, 1959), the protection of the most vulnerable traffic group has to be one of the priorities of local authorities; hence it is one of the operational objectives of our recently launched pedestrian safety initiative "to provide safe school zones and routes."

2. Methodology

Since there is no unique methodology for selecting an appropriate pedestrian crossing facility, the process for its selection revolves around the question of why it is considered desirable to provide specific assistance for pedestrians at a particular location or what it is that the designer seeks to achieve. The second stage, which follows after the overall need has been identified, is to identify a set of facilities that may have a detrimental impact on the safety of all users. Typically, this choice of possible devices is based on the characteristics of the road on which the facility is to be installed and the basic choice sets are outlined in the tables, respectively. Making a decision regarding the selection of a pedestrian crossing type is based on several criteria in order to create a solution that is fair for all the participants.

The main objective of this paper is to develop a case study methodology regarding the selection of the most suitable pedestrian crossing type for the city of Bitola, Macedonia. The most important aim is directed towards obtaining pedestrian safety while bearing in mind the role of pedestrian safety within the current safety goals.

2.1. Geomorphological and transport position of Bitola

The City of Bitola, the second largest city in Macedonia (77,004 inhabitants, Census 2002), is located in its southwest part, on the edge of the Pelagonija valley. It is located at the foothills of the Baba Mountain with the peak Pelister (2601 m), near the Greek border, 13 km away (Ristov, 2015).

The city stretches from both sides of the river Dragor; to the north, it is surrounded by the Bairo hills, as part of the Cloud-Snow mass with the peak Kale (890m); to the south, it is surrounded by the hill Tumbe cafe (744m) as a branch of Neolica, i.e. Baba Mountain. To the east, Bitola is widely open to the Pelagonia valley, and towards the west it is open to the floodplains of the river Dragor, the Gavatian overbearing valley and the peak Pelister. Bitola is spread on a terrain that is sloped from west to east, from 720 m to 585 m, with an average altitude of 652 m. Regarding the traffic situation, it can be said that Bitola is relatively poorly connected. This unfavorable traffic connection had its beginnings in the early 20th century, when with the reshaping of the borders, a large number of traffic routes lost their meaning or completely disappeared. Hence the Bitola gravitational area was reduced and deformed (Dimitrov, 1998).

2.2. Problem identification

According to the standing classification of city street intersections (GUPCB, 1999; SIA, 2016) Vasko Karangeleski St. is classified as the main street. After the appropriate analysis, "mobility versus accessibility", it is determined that this street does not meet the criteria for that classification (Administrative Office of the Primary School Elpida Karamandi Bitola, 2018). Furthermore, according to the data from the report of SIA Bitola for 2003-2016, a total of 38 pedestrians were injured on the said street (13 of whom were severely injured while 25 suffered minor injuries). From this data it can be concluded that there were no injured pedestrians only in 2010 and 2013 while in 2003, 2007 and 2016 an increased number of injured pedestrians was noted (Administrative service at the Pedagogical Faculty Bitola, 2018).The traffic situation particularly deteriorated after the constriction of the primary school Elpida Karamandi, the kindergarten Majski Cvet, the Day Centre for Persons with Disabilities and the Faculty of Pedagogy since a large number of children and students who live east off the street were forced to cross Vasko Karangeleski St. on a daily basis. Today, this street is crossed by 228 pupils (World Bank, 2012; WHO, 2016) who live to the east of the street as well as 380 students who are enrolled as full-time students in the academic year 2017/2018 (Adriazola-Steil et al., 2015). The crossing of the street is made difficult due to the fact that the children, most of whom are still very young, have to cross four lanes at once and deal with the lack of traffic culture by the drivers who fail to follow the rules of pedestrian crossings.

2.3. Pedestrian safety initiative

Following the identification of the problem and the initiative launched by the parents of the children who attend the school, a campaign was organized, in cooperation with the Municipal Council on Road Traffic Safety, professors in the Traffic and Transport Department at the Faculty of Technical Sciences Bitola and non-government organizations in Bitola, to raise awareness among the drivers about the pedestrians' need for safe crossing of streets as well as an initiative to the relevant institutions to help find a suitable solution for the pedestrians on Vasko Karangeleski St. The proposals of the parents and the NGOs are related to the placement of vertical signalization (call buttons), which would be operational during the arrival and departure times of the students in the school; they would enable a relatively fast flow of vehicles on the main street as well as help to avoid any unnecessary stops when there are no pedestrians, as is the case with conventional traffic lights.

In order to acquire information regarding citizens' opinion over pedestrian safety on the analyzed location, we used a questionnaire of six questions and an online survey that involved 770 citizens (Figures 1-3). Namely, gender equality was a key factor since 56.8% of the surveyed were women while 43.2% were men. In terms of age, most of the surveyed were between 31 and 40 (32.6%) and 21 and 30 years of age (25.7%). When asked "How safe is it to cross the street at the pedestrian crossing?" 40.3% answered that it is not safe at all whereas 57.1% answered that it is partially safe.

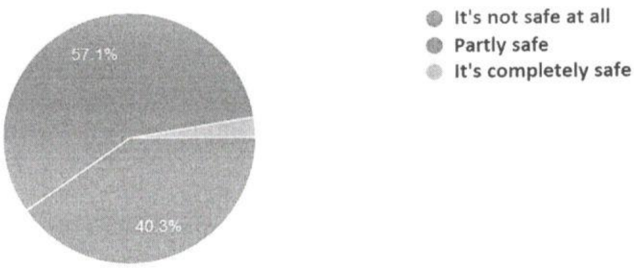

Figure 1. Graphical presentation of pedestrian crossing safety

When determining the main cause for the lack of safety at the pedestrian crossing, the lack of traffic culture among drivers and unmarked pedestrian crossings are listed as the two main reasons. These are followed by illegally parked vehicles in front of pedestrian crossings, its illumination, and ultimately the lack of traffic police and traffic signalization. What is quite evident from the answers of citizens is that despite the fact that the number one reason for the lack of pedestrian safety on pedestrian crossings dominates, all of the given causes contribute to some degree to the reduction of pedestrian safety.

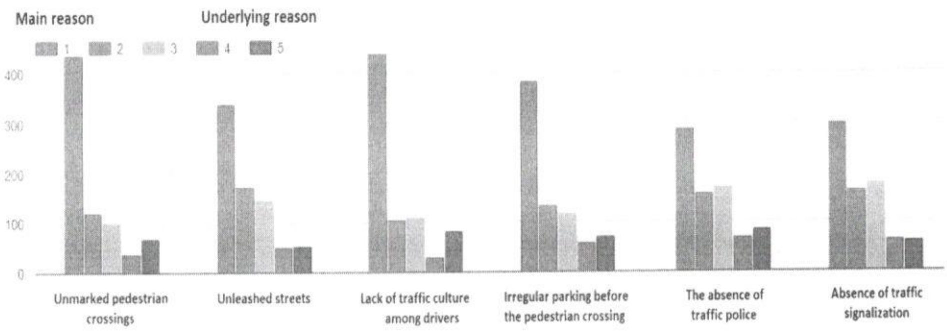

Figure 2. Graphical presentation of pedestrian insecurity while crossing

When asked "Do you think that the four lanes of the street can be safely crossed by a primary school pupil?" a high percentage of 75.8% answered that it would be impossible.

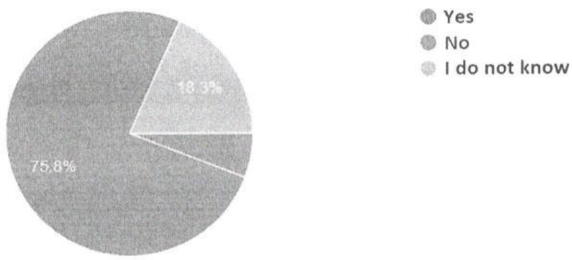

Figure 3. Graphical presentation of meaning regarding pedestrian crossing length

When asked "Do you think that the placement of light signalization (call button) on Vasko Karangeleski St. will increase the safety of the students who use the pedestrian crossing?" almost 86% of the surveyed answered yes, which speaks to the need of regulating traffic on this location.

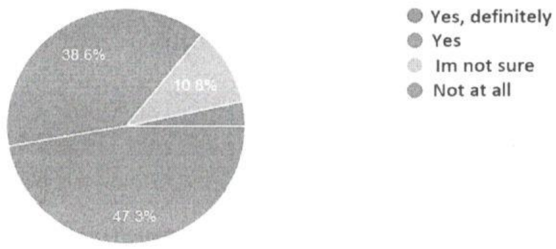

Figure 3. Graphical presentation of meaning regarding signalized pedestrian crossing design

3. Multi-Criteria Decision-Making approach

We have decided to use a multi-criteria decision-making analysis based on the AHP (Analytic Hierarchy Process) approach which synthesizes the aspects of different opinions by weighing up many subjective factors and which studies the unique common result (Saaty& Tran, 2007). The level of consistency allows us to form an adjustment of judgments. At the end of the process we have answered how to best make a decision in a complex and subjective situation with more than a few realistic options. Namely, for the application of the AHP method we set the goal, i.e. three alternatives, adequate number of criteria and subcriteria for precise ranking of the alternative, as in (Table 1). Pairwise comparisons are used to determine the relative importance of each alternative in terms of each criterion (Figure 4).

Table 1. Competing alternatives and criteria

	A1 - signalized pedestrian crossing	A2 - pedestrian crossing with refuge median island	A3 – pedestrian overpass
K1- Safety Criterion	Subcriterion: driving speed (N,1.1) Subcriterion: Traffic flow (N,1.2) Subcriterion: Length of the pedestrian crossing (road width) (N,1.3)		
K2- Price Criterion	Subcriterion: Cost of design (N,2.1) Subcriterion: Cost of construction (N,2.2) Subcriterion: Cost of maintenance (N,2.3)		
K3- Environment & Comfort Criterion	Subcriterion: Noise and environmental impact (N,3.1) Subcriterion: Comfort(N,3.2) Subcriterion: Access for the disabled (N,3.3)		

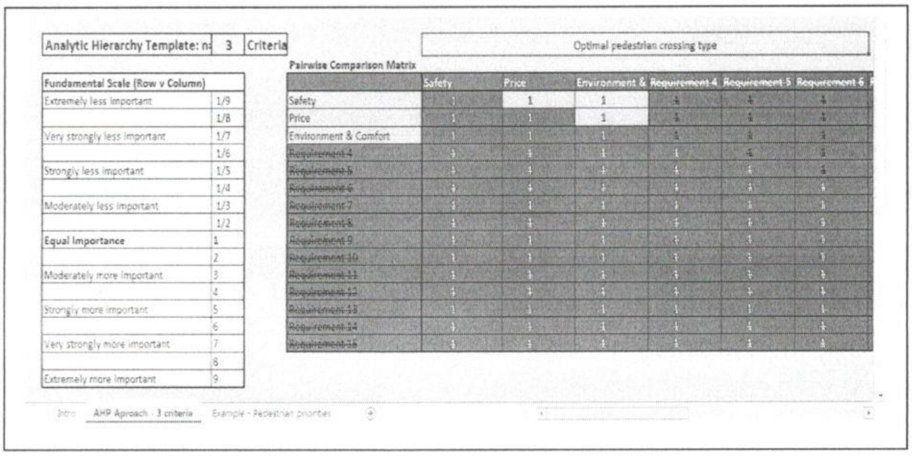

Figure 4. Adopted AHP excel software tool for pedestrian crossing type selection

3.1. Establishment of structural hierarchy

3.1.1. Signalized pedestrian crossings as an alternative

It consists of signal displays, line markings and lighting. In general, fixed-time signals are the rule in urban areas for reasons of regularity, network organization, predictability, and reducing unnecessary delays. In certain, less-trafficked areas, actuated signals (call buttons, loop detectors) may be appropriate; however, these must be programmed to minimize delay, which will increase compliance. The pedestrian crossing signals at midblock crossing locations are widely used in most developed countries. They can be classified into four types: Fixed time pedestrian actuated crossing, Pelican crossing, Puffin crossing and Toucan crossing.

Fixed time pedestrian actuated crossing (Figure 5) is a stand-alone pedestrian actuated (or automatic) signal control. Pedestrians can call green phase by pushing the button, though, traffic must be able to see pedestrian crossing points in time to stop for them. Advance warning signs should be used if visibility is poor. Parking should be removed from near pedestrian crossings to provide adequate sight distance.

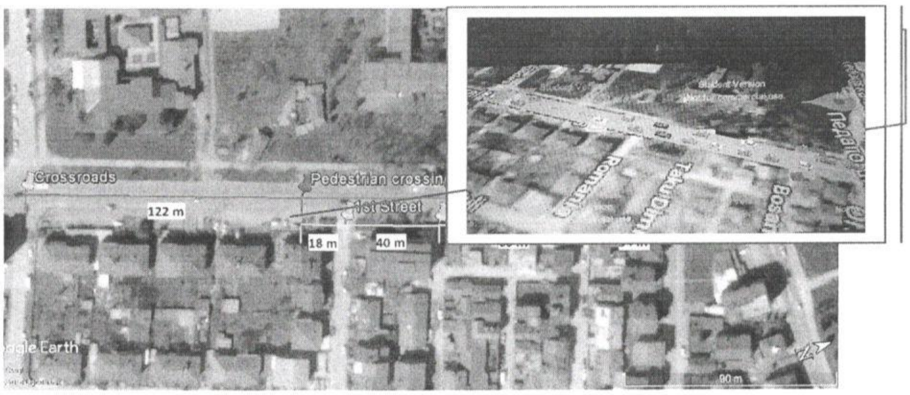

Figure 5. VISSIM microscopic simulation for location under study

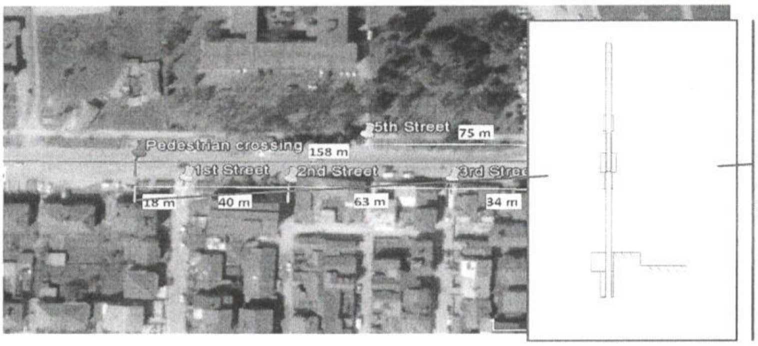

Figure 6. Design of Puffin pedestrian crossing for location under study

3.1.2. Pedestrian crossing with Median Island as an alternative

Crossing a busy road with fast flowing traffic can be very difficult. Pedestrian median islands (Figure 7) can help pedestrians to cross such roads safely by allowing them to cross in two stages and deal with one direction of traffic flow at a time. They can be used where there is a demand for pedestrians to cross the road but where the number of pedestrians is not high enough to warrant a signalized pedestrian crossing. Median islands can be part of no-signalized pedestrian crossing and are usually used on wide, multi-lane roads, with the function of narrowing the lanes for vehicular traffic. They must be clearly visible to traffic both day and night.

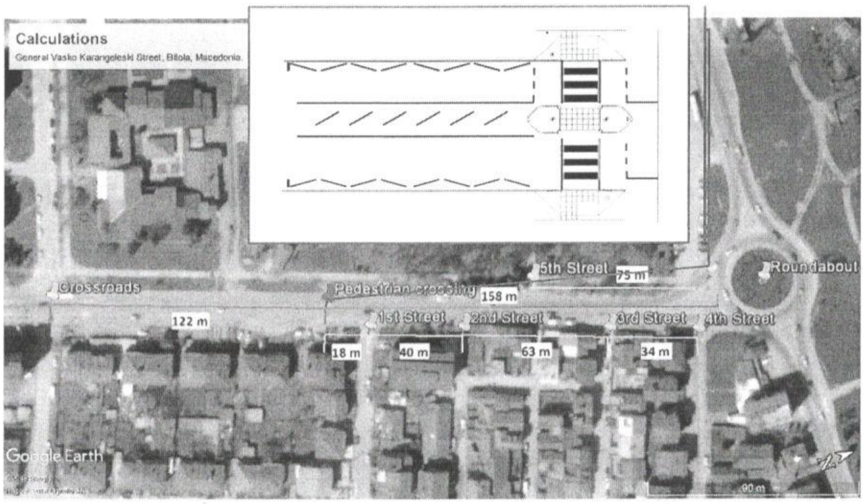

Figure 7. Design of pedestrian crossing type with Median Island for location under study

3.1.3. Pedestrian overpass as an alternative

One effective way of preventing crashes between vehicles and pedestrians is placing them at different levels, or 'grade separating' them. In urban situations where the pedestrian crossing signals would cause congestion or crashes (due to high traffic speeds), a grade separated pedestrian crossing, such as an overpass or an underpass, may be used. Outside of urban areas, in situations where there is pedestrian demand in high speed environments, this treatment may also be applied. Grade separated pedestrian crossings reduce pedestrian crashes but they also have some disadvantages: they are costly, pedestrians may avoid them if there are a lot of steps to climb up or down. What is more, if they are not well-lit and patrolled, they may pose a personal security risk. Pedestrians tend only to use crossing facilities located at, or very near, to where they want to cross the road. Where a lot of cycling traffic is present, a pedestrian underpass or overpass can be used by cyclists as well as pedestrians, but this will require shallow approach ramps and therefore additional land.

3.1.4. Decision hierarchy criteria and sub-criteria

Safety (K1) is a condition in which a pedestrian can normally cross at a pedestrian crossing in the process neither disturbed nor degraded due to various threats and dangers, adapted according to (SIA, 2016).

Driving speed (N1.1) has been identified as a key risk factor in road traffic injuries, influencing both the risk of a road crash as well as the severity of the injuries that result from crashes (World Bank, 2012). Excess speed is defined as exceeding the speed limit. At inappropriate speed, the pedestrian cannot properly estimate the moment at which the vehicle will reach the pedestrian crossing, i.e. the point of intersection between the paths of the vehicle and the pedestrian while the motorist is not able to stop the vehicle on time. The greater the difference in the speed between the pedestrian and the vehicle, the greater the danger to the pedestrian.

If traffic flow (N1.2) saturation results in situations in which the time gap between the approaches of two succeeding vehicles is shorter than the time required to cross the road, the method of stopping the vehicle has to be applied in order to perform the crossing. If traffic is of a higher intensity resulting in even scarcer occurrences of suitable intervals to cross the road, the pedestrians lose patience and recklessly step onto the roadway. The consequences of such actions may be catastrophic and in such situations zebra crossings do not usually match the needs and signalized crossing needs to be constructed. Should traffic lights cause very long queues of vehicles, and pedestrian waiting time exceeds the limit of patient waiting, then the pedestrian crossings are grade-separated, by constructing overpasses.

The length of the pedestrian crossing (N1.3) is in correlation with traffic safety. The crossing time using a longer pedestrian crossing means a longer stay of the pedestrian on the roadway and a higher risk of getting injured. On a multi-lane road the vehicles moving along the right kerb often obscure the view of vehicles that move along the farther lane. This phenomenon is especially noted in cases when small children want to cross the street and the motorists fail to notice them on time. This problem is especially emphasized in the vicinity of schools.

Price (K2) is the value that is put to a product or service and is the result of a complex set of calculations, research and understanding and risk taking ability. A pricing strategy takes into account segments, ability to pay, market conditions, competitor actions, trade margins and input costs, amongst others. It is targeted at the defined customers and against competitors. In forming the criteria of prices for pedestrian facilities, costs of design (N2.1), construction (N2.2), and maintenance (N2.3), have been taken into consideration and studied as separate subcriteria.

Bearing in mind that there are no exact numerical indicators the criterion environment & comfort (K3) serves as an additional assistance to the decision-makers.

Exposure to noise (N3.1), in everyday urban life is considered to be an environmental stressor. A specific outcome of reactions to environmental stress is a fast pace of life that also includes a faster pedestrian walking speed. On zebra crossings and signalized crossings pedestrians are exposed at a high noise level whereas in underpasses and overpasses they are much better protected. The closer the vehicles are to the pedestrian crossing and the larger their number, the greater the influence of noise. It is most expressed at the peak hours when the greatest number of vehicles and pedestrians is on the road.

The sub-criterion aesthetic and environment (N3.2) considers the negative impacts of pedestrian crossing construction on the environment, changes of the streetscape, unpleasant experiences as well as a feeling of personal protection.

The concept of accessible design for disabled persons (N3.3) ensures both direct access, i.e. unassisted, and indirect access, that is compatibility with a person's assistive technology (for example, computer screen readers). This intends to make everything accessible to all people regardless of their having any disability or not.

4. Conclusions

The crossing opportunities available to pedestrians on the studied location are below the desired level of service. Historical records of crashes in the vicinity of the location are a serious factor that indicates the need for providing crossing assistance. The methodology of selecting a pedestrian crossing proposed by this research is comprehensive. For this purpose an adopted AHP excel software tool has been developed and a VISSIM microscopic simulation was used to model the alternatives under a range of likely pedestrian volumes and a range of likely vehicle volumes. The process of alternatives evaluation by calculating the weight values of criteria and alternatives has been performed by comparing the pairs of criteria, based on the questionnaire results for different target groups of citizens, professionals, disabled and healthy persons. Namely, professionals give weights to the traffic safety and priority to the overpasses. Regarding environment and price the best alternative is Median Islands. Both healthy and persons with disabilities equally value signalized pedestrian crossing.

Analysis results are in correlation with the design principles showing that on undivided four lane main street (two lanes per direction), without allowed side parking, at a speed limit of 50 km/h, and with the distance of 150-200 meters to the next intersection light signals or median islands are recommended. Bearing in mind the traffic culture of drivers, we assume that the introduction of signalized mid-block crossing with pedestrian-actuated control and fixed-time operation is the optimal type for the location under study.

The methodology and the results from various research allow tests to be administered on possible scenarios in order to decide on the best type of pedestrian crossing. However, we must take into account all the specific features of the location so as to introduce the best conditions, both in terms of space and maintenance plan, as well as suitable traffic signalization.

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