The examination of road traffic flow and accident risk of pedestrian crossing in the surroundings of zebra crossings

Summary of the thesis for PhD

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1. Introduction of the research topic

1.1. **Timeliness of the research topic**

Among the different branches of transport, most accidents with personal injuries happen in road traffic. In the countries of the European Union, 40,000 people died and 1.7 million got injured during road traffic accidents in 2000. In Hungary since the year 2000, the number of road traffic accidents and the number of casualties have been continuously increasing. The number of pedestrian casualties in road traffic accidents has been close to 4000 persons/year in the past few years, which is fifth of all road traffic accidents with casualties, but examining the lethal accidents in the past ten years, the number of pedestrians is more than fourth of all fatalities in road traffic accidents. The number of serious or lethal accidents amount to almost half of all pedestrian accidents. Road traffic accidents with personal injuries are caused in 50% by pedestrians and in 50% by drivers.

The European Union issued a directive about the reduction of pedestrian fatalities in road traffic accidents. The planned reduction of fatalities in shown in Figure 1.

![Trend of the European Pedestrian Fatalities and the Draft Phase-In](source: IRTAD)

Figure 1: The EU-directive on the reduction of pedestrian fatalities

In contrast with European tendencies, the number of road traffic accidents and the number of casualties has been continuously increasing since the year 2000 (Figure 2). The number of road traffic accidents increased with 1% in 2006 compared to the previous year, the number of fatalities increased with 2%. Tenth of road traffic accidents are caused by pedestrians; in case of pedestrian accidents, they are caused in 50% by pedestrians and in 50% by drivers.

Previously very few studies have been made about the traffic custom and behaviour of pedestrians, the mutual impact of vehicles and pedestrians on each other and the causes of accidents. In order to prevent road traffic accidents, one important step is the study of the behaviour of the participants of traffic and the analysis of their conduct, customs and decision-making process. When examining traffic customs, the behaviour simulation models can provide help. [5]
The reasoning for the choice of topic is summarized as follows:

- the analysis of the frequency and gravity of road traffic accidents and pedestrian accidents within,
- the determination of the accident risk of pedestrian crossing and the qualification and classification of zebra crossings according to accident risk,
- the study of the ever-changing customs and behaviour of the participants of road traffic

![Figure 2: The number of road traffic accidents with casualties and the number of casualties in Hungary between 2000 and 2004 [63]](image)

1.2. **Objectives and method of research**

In order to prevent pedestrian road traffic accidents, the most important factor is the increase of the security of zebra crossings:

- the adequate choice of the type of crossing,
- the improvement of the development of the crossing,
- the decrease of the speed of vehicles,
- the improvement of perception and recognition.

The planning principles during the development of zebra crossings:

- the decrease of the speed of vehicles,
- the assurance of visibility (vehicle-pedestrian),
- the decrease of the duration of crossing (distance, time)
- the avoidance of excessive restrictions not tolerated by pedestrians. [81]

The objective of the thesis is the improvement of the safety of pedestrian crossing. The tasks to be completed are as follows:

- the analysis of the customs and behaviour of traffic participants,
- the qualification of the risk of crossing,
- the simulation modelling of the flow of traffic,
- the assessment of the results of the simulation calculations,
- the qualification of the different types of zebra crossings according to the risk of crossing.
Based on the specialized literature and due to the limits of the simulation models that I encountered during my research, in order to complete the objected task I created a new simulation model, which is called SIMPAS (Simulation de Passage Piéton).

The basic requirement towards the SIMPAS simulation model is that it should facilitate the collection of data about:

- the behaviour of the participants of traffic,
- the accident risks (actual accidents, qualified events) and
- the quality of road traffic flow.

Indirectly it should facilitate:

- the choice of the most adequate type of zebra crossing for safety and traffic requirements
- the safe testing of the new crossing.

The SIMPAS model presenting the behaviour of the human participants of traffic is based on the mathematics methods of qualifying set theory and neural networks. With the use of qualifying set theory, fuzzy logics, in the modelling of the decision-making process, it is possible to create models and algorithms that more effectively map natural human intelligence and require less calculation at a given accuracy.

2. Overview of specialized literature

After the decision on the topic of the research, I examined and valued the specialized literature available. For this I used the transport publication database of the Institut National de Recherche sur les Transport et leur Sécurité (INRETS) and the dynamic development of internet search programs and the electronic versions of publications becoming available. The publications used are grouped according to the topics of the thesis.

The method of simulation modelling

The practice of computer-based simulation modelling and its sphere of application is continuously expanding with the increase of computer capacity. The most important general elements of the method of simulation modelling, the technical devices, the creation of random numbers with various distribution and the verification of models are described by MEIER, NEWELL and PAZER [73] and HORVÁTH, SZLÁVI and ZSAKÓ [43], the simulation of discrete systems by TARLÓS [89], and the basics of probability calculus by KÁTAI [54]. The principles of the functioning of stochastic systems are described by KARLIN and TAYLOR [53], and the methods of simulation examination described by BUSZLENKO [13].

The simulation modelling of road traffic

The computer-based simulation modelling of road traffic was started in the United States in the 1960s in order to study the flow of traffic on highways and examine the general principles [46].

In the classical simulation models, empirical relations about the flow of traffic are calculated from the measured and perceived data with mathematical (in most cases statistical) methods [15][17][46][98].
The different characteristics of the participants of traffic and the random processes in the models are secured by random numbers of given dispersion and distribution [95]. As a consequence, classical models are usually adequate only for the reproduction of the perceived system and the behaviour of the participants of traffic.

The main characteristics and relations examined with classical traffic simulation models are the following: the characteristics of traffic flow at a given road or road network: the level of traffic flowing through, the frequency of vehicles, the average speed of vehicles, the fundamental equation, the course of traffic operations VÁSÁRHELYI [95] and WIEDEMANN [98], the characteristics of the concurrence and crossing of traffic waves: capacity, retardation, the creation of different infrastructures, the comparison of traffic control methods CERTU [15] and FI [21] [22].

The creation of simulation models for the examination of the behaviour of the participants of traffic, especially drivers, was started in France in the 1990s. The most well-known model is ARCHISIM [51].

In recent years, various models were made for the examination of pedestrian traffic, these provide help mainly in the measuring of traffic establishments (subways, platforms, traffic areas etc) BERÉNYI [8], the time requirement for pedestrian crossing TEKNOMO, KARDI, TAKEYAMA, INAMURA [90] and the analysis of escape routes and times in case of the possible occurrence of danger situations KÜPFEL, MEYER-KÖNIG, WAHLE [67]. The models analyse the flow of pedestrian traffic GIPPS, MARKSJO [27], HELBRING, MOLNÁR [30], HELBRING, MOLNÁR, FARKAS, BOLAY [31], and the conflicts of pedestrians with each other HELBRING, FARKAS, VICSEK [32][33], TEKNOMO, KARDI, TAKEYAMA, INAMURA [90], BLUE, ADLER [10]. They examine the relation between vehicles and pedestrians ZHANG, WANG, LI [100], the control of pedestrian crossing LIU, DA SILVA, DA MAIA SECO [72], and the pedestrians’ decision about crossing KEBEL, KÜPFEL, WAHLE, SCHRECKENBERG [55].

The models of the specialized literature provide two solutions for the modelling of the movement area of pedestrians: pedestrians move in a vector area that permits optional directions for movement [47][90], or the area is divided into elementary cells and pedestrians move with discreet steps from one cell to the other [55][67][83]. The size of the cells adjusts to the size of the area occupied by pedestrians, on average 40x40 cm [82] or 48x28 cm [100]. Fields are often used to influence the movement of pedestrians. [32][33][67][77].

**Neural networks and qualifying set theory**

Already since the 1990s there have been research in the United States and in the European Union in connection with the automation of the control of vehicles [11]. The basic principles and possibilities of technological application of neural networks are described by HORVÁTH [42]. The change of the characteristics of road traffic flow was examined with the use of neural networks by KISGYÖRGY [57].

The founder of qualifying (fuzzy) set theory and logics is professor ZADEH [99]. The principles of qualifying set theory is described by BOUCHON-MEUNIER [12], COX [18] and ZIMMERMANN [101], its application described by KÓCZY és TIKK [62], GACÓGNE [26], BARANYI and YAM [7].

The application possibilities of neural networks and qualifying set theory is described by BORGULYA [11], VÖRÖS [97], LIN and LEE [71].
The behaviour of the participants of traffic in the surroundings of zebra crossings

The change of traffic safety must be continuously examined. [68]. The source for this is provided by accident data and the perception of the behaviour of the participants of traffic.

The data collected by the Hungarian Central Statistical Office includes the changes in the number of accidents and casualties and the gravity of injuries. [64]. The state of traffic safety in Hungary and the safety of inner city junctions are investigated by HOLLÓ [36][39]. The analysis of the statistics on pedestrian accidents and the conclusions that can be drawn are described by FONTAINE, GOURLET and ZIANI [24][25]. ASALLY examined pedestrian accidents and the behaviour of pedestrians according to age groups and elaborated suggestions for the increase of traffic safety [5][6]. The traffic of pedestrians, and road crossing was examined by ROBIN [81], and the theoretical modell of decision-making based on accidents was made by O’NEILL [76]. The publication of KOTUKI [66] describes the results of the analysis of pedestrian accidents in Hungary, the death risk of different age groups are analysed by HOLLÓ [38]. The causes for children accidents on the road were investigated by PAPPNÉ [78]. The traffic of old people and their exposition to danger was examined by HÉAM, DEJEAMES [29] and PAPPNÉ [80], the typical accidents and driving mistakes of old drivers by SISKA [86], the analysis of the traffic accidents of old pedestrians by PAPPNÉ [79].

The OECD publication [69] includes the results of the examination of the mobility arising from traffic necessities and the consequences of the aging of society.

CARRÉ and JULIEN describe a method for the measuring and analysis of pedestrian traffic and its risk factor [14]. Traffic risk is examined by BÉNYEI [9] and HOLLÓ [37]. The motivations behind pedestrian road crossing are described by HENDERELSON [34], the possibilities of further improvement of traffic light zebra crossings are examined by LEVELT [70]. The traffic customs of drivers and pedestrians were studied by HERMAN, HUANG and CYNECKI [35]. The conflict situations between pedestrians and drivers were analysed by TAKÁCS [88]. The experiences on traffic flow anf traffic safety of raised crossing are described by a study of CETUR [16].

The publication of French INRETS [45] shows the objectives and results of traffic psychology research. The human factors of traffic safety are examined by DULIN [19][20], ANDICS [4] and SISKA [85], accidents caused by beginner drivers were analysed by HOLLÓ, SISKA and VLASZÁK [40], the relationship between road line, traffic management solutions and traffic safety were examined by KOREN [60][61].

The creation of zebra crossings

For the creation of road infrastructure, the transport branch standard [56] of the Ministry of Economics and Transport, the Road Technological Regulation [93], and the 20/1984. (XII. 21.) Ministerial Decree [2] on road traffic control and the placement of road signs must be applied.

The creation of junctions and zebra crossings are described by NAGY and SZABÓ [75], and FI [23]. For the planning of traffic light traffic control, the guidelines set in Road Technological Regulation [94] must be applied. The creation of raised crossing is described in the publication of French CERTU[16]. The principles and indicators of traffic flow are included in HCMT [28].

The rules for traffic are set by the several times modified 1/1975. (II. 5.) Ministerial Decree, generally known as the Highway Code [1].
The conflict technique study of road traffic and its application is described by JÁKLI [50]. The methods for the audit of road traffic management solutions are outlined by JANKÓ [49].

**The working dynamic characteristics of vehicles**

The calibration of traffic simulation modell and the required vehicle dynamic characteristics are found in the books of TERNAI [91], ILOSVAI [44], KOLLER [59] and NAGY and SZABÓ [75].

### 3. New scientific results and thesis

The new scientific results elaborated in the thesis for Ph.D. are summarised in the following five thesis:

1. **I elaborated a new way of determining the accident risk of pedestrian road crossing and its measuring method with simulation calculation. The estimated accident risk permits the study of not-yet-happened accidents and the evaluation of their causes through the use of simulation examinations.**

   The indicators presently used calculate only with the accidents that have happened and have been registered and don’t take into consideration the „almost accidents” and the conflict danger situations, where a participant of traffic had to more or less change its motion in order to avoid the accident. The data of the accident scene investigations of accidents with casualties do not always show the causes for the accidents. For this reason they only provide an approximation for the actual accident risk of road traffic.

   The estimated accident risk of pedestrian crossing is a factor of the probability of the collision of vehicle and pedestrian and the estimated gravity of the accident:
   \[
   \text{Estimated accident risk} = f(\text{accident probability}, \text{estimated gravity})
   \]

   The probability of the accident is determined by the relative situation of the participants of traffic, their motion, the traffic management solution characteristic of the crossing and the method and rules of traffic control.

   The probability of the accident shows the level of the possibility of the pedestrian and the vehicle colliding. It is highly important to examine the situation where by starting to cross, the pedestrian forces the approaching vehicle to slow down, thus give way, as in most cases of pedestrian crossing accidents, the pedestrian did not judge correctly the distance and motion of the vehicle, thus the stopping distance; or the driver did not follow its obligation to yield. The main factors influencing the gravity of the accident – based on the expected injuries of the pedestrian – are as follows: the speed of the vehicle before the collision and the physical state of the pedestrian, which is in close relationship with their age.
2. Applying the methods of fuzzy logics and neural networks, I elaborated the SIMPAS modell, the behaviour simulation modell of the decision-making process of the human participants of traffic about their movement change.

The simulation modells for the examination of traffic flow can be elaborated from two perspectives:
- the description of the data from the perception of the participants’ movement change with empirical equation, the calibration of which is done with co-efficients.
- through the modelling of the functioning of the human participants and their strategy for decision-making upon the information coming from the environment (Figure 3.).

![Figure 3: The modell of the functioning of the participants of traffic](image)

I elaborated the sorting in mathematical and operational terms of the simulation models of road traffic flow, and defined the criteria and main characteristics of behavioural modells.

I prepared the behavioural simulation modells about the decision-making mechanisms of the human participants of traffic (Figure 4).

![Figure 4: The main influencing factors of the decision-making of the participants of traffic](image)

The degree if rule-following behaviour and assumption of risks of the participants of traffic depend on various factors. In the SIMPAS modell, the degree of rule-following is a momentous factor, that has a personal and varying average adjusting to age groups and changing with respect to the restriction period.

Pedestrians change their movements according to their own customs in order to reach their destination, being under the influence of the environment and more or less adapting to it (Figure 5). Thus time-to-time they process the information they can interpret from the environment and make decisions. A decision-making cycle has the following three elements:
1. The collection and evaluation of information (fuzzyfication)
2. The creation of strategy (neuro-fuzzy process)
3. Execution (defuzzyfiation)
The pieces of information used in qualified form at pedestrian decision-making:
- frequency of pedestrian flow,
- distance of vehicle,
- speed of vehicle,
- frequency of vehicle traffic flow.

The pieces of information used in qualified form at driver decision-making:
- distance of zebra crossing, vehicle and pedestrian,
- speed of vehicle and pedestrian,
- change of safety gap.

I elaborated the computer program necessary for the application of the SIMPAS simulation modell, suitable for the examination of the traffic flow of zebra crossings and the analysis of accident risk.

The types of zebra crossings in the SIMPAS computer program are as follows: road section without designated zebra crossing, designated crossing, raised crossing, pedestrian island and crossing with push button traffic lights.

The data provided for analysis by the simulation program are:
- vehicles: running time, lost time, number of stops, changes in rule-following, speed of vehicle at the zebra crossing,
- pedestrians: waiting time before crossing, degree of accident risk at crossing.
3. With the help of SIMPAS simulation model and the computer simulation program, I defined the pedestrian waiting times and the lost time of vehicles in case of zebra crossings with different traffic management solutions.

The quality of traffic flow was examined in the range of 200-700 vehicle/h and 200-600 pedestrian/h (Figures 6 and 7.). In case of traffic flow larger than this, push wave and traffic jam developed.

Figure 6: Average waiting time in case of 400 p/h pedestrian traffic flow

Figure 7: The increase in average running time for vehicles in case of designated zebra crossing

Waiting time of pedestrians are determined by two factors: the accident risk estimated on the basis of intervals between vehicles and the speed of the vehicle and the momentarily risk-taking of pedestrians.

The intervals between vehicles are in connection with the level of traffic flow, the method of traffic control (obligation to yield) and the type of the crossing. (traffic management solution)
4. With the application of the SIMPAS simulation modell and the computer simulation program, I defined the accident risk of the crossings with different traffic management solutions in case of various traffic levels. Based on the results of simulation examination, I prepared the evaluation of the different zebra crossings from the respect of accident risk.

With the application of the behaviour simulation modell I did a comparison examination of the zebra crossings of different traffic management solutions, the level of traffic and the accident risks.

The data for simulation calculation was collected on a two-way, two-lane road section with parking opportunity at the edge. On this road the maximum speed permitted is 50 km/h (Figure 8.).

![Figure 8: Average accident risk at crossings with different traffic management solutions at constant pedestrian flow of traffic](image)

5. Based on the results of simulation examination I discovered the relationship between the rule-following and risk-taking of the participants of traffic and the risk of traffic accident

The degree of rule-following and risk-taking of the participants of traffic is not constant, but varies according to the quality of traffic flow. The rule-following of drivers is influenced by the lost time compared to running time, the risk-taking of pedestrians is influenced by the length of waiting time. Consequently in case of light vehicle and pedestrian traffic, rule-following is on a high level whereas risk-taking is on a low level. As the level of traffic increases the lost-times and waiting times are lengthened, thus the level of rule-following decreases and the level of risk-taking increases.

I proved with simulation calculations that the increase of accident risk and the level of traffic in case of light and medium traffic is proportionate, whereas in case of heavy traffic, the average speed of vehicles decreases in the surroundings of zebra crossings thus the indicator of accident risk does not increase. (Figure 9.)
4. The practical utilisation of the scientific results of the thesis

The main methods for the decrease of road traffic accidents are as follows:
- Increase of efficiency of education and training,
- The choice of crossing adequate for demands,
- Development of infrastructure,
- Modification and specification of regulation.

On the field of traffic planning

Considering the changes in traffic demands and customs, the effectiveness of traffic control must be inspected continuously and the invention and application of increasingly safer solutions is needed. The safety of a pedestrian crossing is described by the frequency of the different accident risks. The SIMPAS permits the record of not only the actual accidents but the different accident risks as well and it helps in the choice of crossing adequate for the demands of traffic.

Choosing the type of crossing

The SIMPAS computer program permits the examination of the traffic flow and estimated accident risk at the five types of crossings (described at the model) with different traffic management solutions. The understanding of the relationship of pedestrian crossing, level of traffic and estimated accident risk helps the planners of traffic in choosing the type of crossing.

Development of infrastructure

The surroundings of crossings should be developed so that pedestrians – especially children – could cross the road on the safer, designated crossing. The occurrence of pedestrian accidents is highly influenced by parking at the crossing and the method of traffic control [17].
Adequate traffic management solutions of crossings (e.g. public lighting, length of visible road section, regulation of parking etc.) can increase the recognizability of vehicles before the start of crossing. Thus visibility and lisibility must be considered at the development of road crossings.

**On the field of education and training**

In university education the simulation program based on the SIMPAS modell provides an opportunity for students to conduct measurements with different parameters in laboratory practice class and evaluate the results finding and checking relationships between them.

**In research**

In order to achieve safer road traffic, it is vital to know the behaviour of the participants of traffic and the influence of the environment. When elaborating SIMPAS, it was an important objective that – by the simple changing of the parameters - it would provide an opportunity for the try-out of different traffic psychology behaviour modells, traffic management solutions and infrastructures.

**Improvement possibilities**

The behaviour of the participants of traffic (especially the degree of rule-following) in great extent varies in the examined European countries. The SIMPAS modell and the computer simulation program permits the application of the different traffic customs and behaviours and the comparison and analysis of the traffic situations, the quality characteristics of traffic flow and traffic safety. Due to its open structure, the modell permits the inclusion of further factors influencing traffic behaviour (e.g. pedestrian groups).

The impact study of behaviour not only at crossings but in junctions and road sections of different traffic management solutions may serve as topic for further research.

In the traffic behaviour of children, the teaching of being careful and circumspect has a major role. Following a more detailed elaboration of the graphic surface of the SIMPAS computer simulation program (e.g. 3D animation), the wider introduction of the impacts of different traffic behaviours and their presentation in video film or in an interactive method becomes possible. The impact of changing weather on traffic flow and accident risk. The change of road surface or adhesion and thus the alteration of the acceleration and braking ability of vehicles. The consideration of the decrease in the range of vision at the choice of speed of vehicles and the estimation of accident risk.
5. Publications of the writer linked to the thesis

Printed university lecture notes

Foreign language article published in Hungary

Foreign language presentation in international conference publication

Hungarian articles


Hungarian language presentation in conference


Conference presentation published in extracts
Juhász J.: Modélisation comportementale des piétons, Journée d'étude, 21 juin 2004 - INRETS – Arcueil

Oral presentation