DOI: 10.1051/matecconf/201712201007

Pedestrian safety management using the risk-based approach

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Abstract. The paper presents a concept of a multi-level pedestrian safety management system. Three management levels are distinguished: strategic, tactical and operational. The basis for the proposed approach to pedestrian safety management is a risk-based method. In the approach the elements of behavioural and systemic theories were used, allowing for the development of a formalised and repeatable procedure integrating the phases of risk assessment and response to the hazards of road crashes involving pedestrians. Key to the method are tools supporting pedestrian safety management. According to the risk management approach, the tools can be divided into two groups: tools supporting risk assessment and tools supporting risk response. In the paper attention is paid to selected tools supporting risk assessment, with particular emphasis on the methods for estimating forecasted pedestrian safety measures (at strategic, national and regional level) and identification of particularly dangerous locations in terms of pedestrian safety at tactical (regional and local) and operational level. The proposed pedestrian safety management methods and tools can support road administration in making rational decisions in terms of road safety, safety of road infrastructure, crash elimination measures or reducing the consequences suffered by road users (particularly pedestrians) as a result of road crashes.

1 Introduction

Poland is considered the EU's most dangerous and least friendly country for pedestrians. Figures show that in Poland between 2004-2015 there were 160,000 fatal and injury crashes involving pedestrians in which 17,800 pedestrians were killed. The causes include dangerous driver behaviour (such as: speeding, red light running, not respecting pedestrians' right of way, overtaking at zebra crossings, etc.), dangerous pedestrian behaviour and poor road infrastructure. Pedestrian safety is a recognised problem and one that has been the focus of road safety efforts for a number of years. There are road safety programmes and strategies both at country and regional level in Poland which give pedestrian safety a priority making it one of the main goals of Poland's efforts towards vision zero [1,2]. While Poland has been able to gradually reduce pedestrian fatalities (in 2008-2014 pedestrian deaths decreased by 40%) the results are still far from the expectations.

To ensure that pedestrian safety is handled properly, systemic measures are required designed to identify and assess the hazards and where they occur. This provides the basis for identifying the key problems and proposing effective measures relevant to the problems. The

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pedestrian safety management process should include a number of stages and reflect all phases of a road accident and all contributing factors such as the road user, vehicle, road infrastructure and pedestrian infrastructure and the roadside [3]. To that end extensive knowledge is needed on how the man-vehicle-road system operates putting special emphasis on the pedestrian being the most vulnerable road user.
The paper proposes a pedestrian safety management system for different areas and levels of management. It builds on a risk management method implemented for pedestrian safety management purposes. Special attention was paid to tools that are designed to support the pedestrian safety management system across all levels, with the focus on tools for risk assessment as a key step in pedestrian safety management.

2 Theory

As road transport continues to grow, new challenges emerge for pedestrian safety that call for appropriate response to the increasingly high risk for pedestrians. Over the last few decades road safety approaches have evolved significantly starting from user focus and the 3E approach. The term "safe system" gradually emerged along with beginnings of an interdisciplinary and systemic road safety management [4]. Pedestrians were now viewed as sensitive and vulnerable road users that must be given priority in road traffic. Today to ensure that road safety and its most vulnerable users are given the treatment they deserve we need a comprehensive and multi-sectoral approach taking a multi-faceted view on road crashes, their causes and circumstances suggesting the most effective ways to prevent those crashes from happening in the future [4,5].

A systemic approach to pedestrian safety management was proposed earlier in [1,6]. It is founded on the risk-based method with elements of behavioural [7–9] and systemic [10,11] theories. When applied to road engineering they help to establish a formalised and repeatable process which integrates risk assessment and risk response to the hazard of fatal and injury pedestrian crashes. The concept is presented in Figure 1.

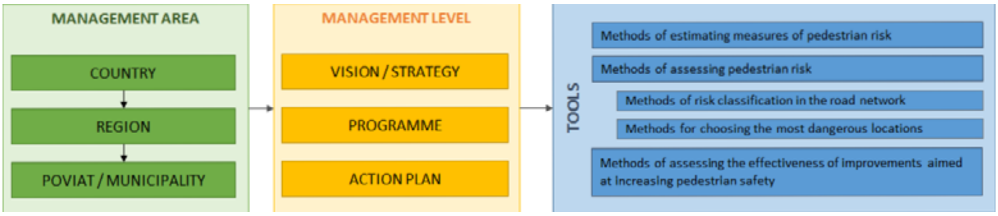

Fig. 1. Risk-based pedestrian safety management concept [6].

The proposed method distinguishes three areas of pedestrian safety management. At the country level, represented by central authorities, key decisions are made: road safety programmes, legislation on safety and decisions that will trickle down to the lower levels. Implementing the decisions is the responsibility of central bodies tasked with coordinating specific issues such as organising the road safety system, road traffic enforcement, road infrastructure, legal solutions, road rescue and education, information and communication. The decisions taken at lower levels (region, county, municipality) take account of national policy. Those responsible for the implementation include road authorities, transport operators or other delivery bodies. Because they have less power, lower level bodies can do less compared to the national level. Despite that, they can manage pedestrian safety in the following areas: road safety structures, road user education, traffic enforcement and control, road infrastructure and rescue.

Whatever the management areas, the actions should be delivered both at the strategic, tactical and operational level [1,3]. At the strategic level political decisions are taken and long-term goals and objectives are formulated that are the basis for pedestrian safety management at the lower levels. The tactical level explains how strategic level goals should be delivered in the mid-term by defining ambitious yet achievable goals and identifying the most effective measures. The operational level implements concrete measures that are undertaken directly by road authorities, town planners, transport operators and road users. Road safety system users are influenced at the particular levels by road safety strategies, programmes and action plans that come with funding systems. To ensure that the influences are effective, support is needed in the form of tools, procedures and methods that help with decision-making and responding to pedestrian safety needs. At this stage the concept moves into the risk-based approach in risk engineering, a formalised and repeatable procedure integrating risk analysis and risk assessment and response to eliminate risk or bring it down to acceptable levels [1,12]. The approach distinguishes two basic steps: risk assessment which includes identifying risk context, sources of hazards and evaluating risk measures; and risk response using a set of tools, methods, procedures and processes that help to decide which types of risk should be avoided, transferred, reduced or accepted [3].

3 Tools for pedestrian safety management

Drawing on the authors' concept of three-level pedestrian safety management using the risk-based method (Fig. 1), the tools proposed in this paper can be used to aid the delivery of risk management steps. These include:

- Risk assessment through: analysis of the problems and selection of risk groups (segmentation) based on historical data, estimation (forecasting) of safety measures (e.g. number of fatalities), risk classification for specific areas or road sections under analysis, road safety audits, inspections and controls, identification of hazardous sites.
- Risk response through: selection of the most effective solutions for pedestrian safety, implementation of the solutions and enforcement, monitoring and evaluation, informing road users, legislations, guidance and recommendations, communicating risk to the public.

Selecting the right and effective tools is important because risk reduction or elimination can only be achieved thanks to a thorough risk assessment. In particular, strategies, programmes and action plans, all of which are elements of pedestrian safety management at the different levels, must build on a detailed risk assessment designed to set goals and targets in priority areas where urgent intervention is needed. This is why the paper focuses on this risk management step. A number of examples of tools can be presented that can be used for risk assessment. Some of them are presented below.

3.1 Methods for estimation of pedestrian safety measures at strategic level

Estimating pedestrian safety measures is possible using numerical models, which helps to study the relation between pedestrian safety measures and variables describing an area in question and its residents. This tool provides the basis for strategic road safety management which should build on long-term forecasts of safety measures and understanding how the activities (investments, legislation, etc.) affect road safety.

At the strategic level risk is assessed using societal risk referring to entire groups of society in a given area. Jamroz [3,13,14] proposed a two-component model used to calculate general societal risk, where the estimated measures are the result of the product of exposure to a specific type of risk and mean consequence of a selected category in a unit of time. Building on the model, efforts can be undertaken to develop models for estimating pedestrian fatalities at country or regional level. Jamroz et al. [1] developed a country-level model (Fig. 2) for estimating pedestrian fatality rate RFR_p on the basis of demographic, geographic, economic, societal and transport parameters that characterise analysed countries in the years

 DOI: 10.1051/matecconf/201712201007

of the analysis (a total of 321 country-years were analysed). With its high regression coefficient (> 0.9), the model helps to estimate the country-level pedestrian fatality rate based on the available data.

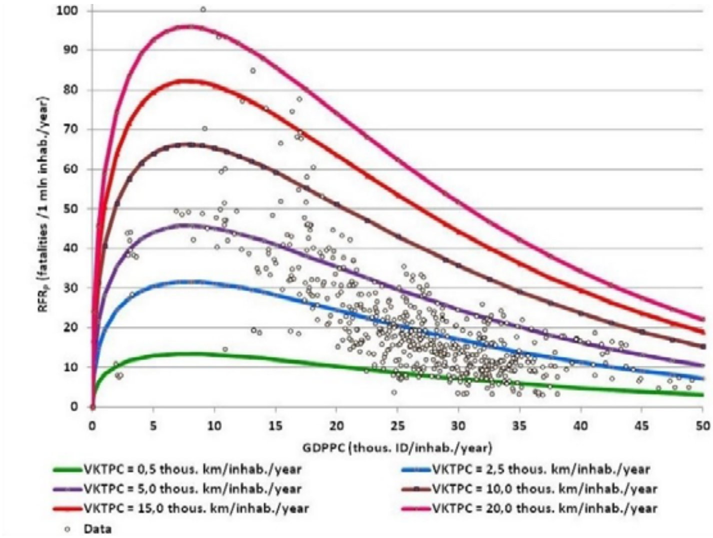

Fig. 2. The fatality rate in relation to the level of socio-economic development modelled at country level [1].

A similar approach to modelling the pedestrian fatality rate was applied when studying Polish sub-regions that are consistent with NUTS-3 territorial units. The collected data included population, areas, gross domestic product, motorization rate and length of paved roads. Analyses were conducted for 66 Polish sub-regions in the years 2009-2012. Two pedestrian safety measures were analysed: pedestrian fatality rate expressed with the number of pedestrian fatalities per population RFR_p and pedestrian fatality rate expressed with the number of pedestrian fatalities per area RFR_a. Further analysis helped to develop a model (1) for RFR_a based on the relations observed in an analysis of correlation. The model's coefficients have a very high level of significance (p < 0.1) and coefficient R^2 was obtained in the order of 0.95. The results are presented in Fig. 3.

$$RFR_a = \alpha_1 * GDP_{pA}^{\alpha 2} * exp(\alpha_3 * GDP_{pA} + \alpha_4 * DOP + \alpha_5 * DCR) \quad (1)$$

where:
- RFR_a – pedestrian fatality rate (fatalities/100 km^2/year),
- DOP - population density (population/km^2),
- GDP_{pA} - gross domestic product per area in m PLN/km^2,
- DCR - the number of passenger cars per km^2,
- $\alpha_1, \ldots, \alpha_5$ - equation coefficients selected to the model through analysis.

In the case of a regional model, due to limited data (only 3 year data on 66 Polish sub-regions) and too few explanatory variables to be analysed (e.g. while vehicle-kilometres travelled would probably be a better predictor variable, they are not easy to obtain at the level of sub-regions) the model should be treated as a point of departure for further research to help identify which factors may affect the pedestrian fatality rate in Polish sub-regions. However, by using a territorial division that is common across the European Union, we can also use data from other countries. The resulting model could be used for forecasting long-term changes in pedestrian fatalities on Polish roads and those in Europe's regions and sub-regions.

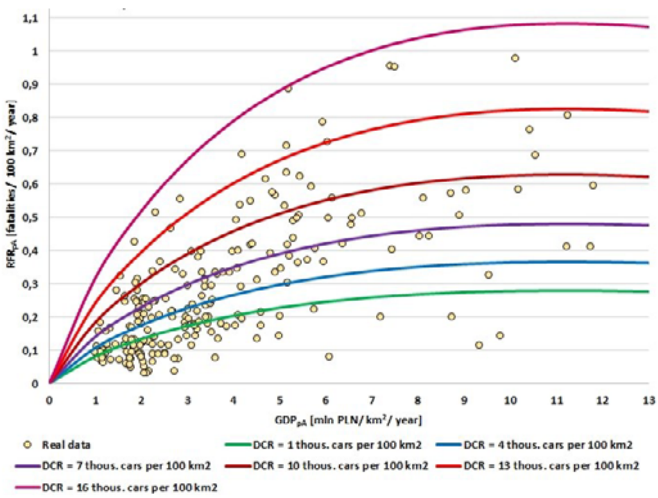

Fig. 3. The fatality rate in relation to the level of socio-economic development modelled at regional level for Polish sub-regions NUTS-3.

Some simple modelling was also conducted for Polish cities that are county capitals. Although the results did not produce satisfactory results, they helped to outline the relations between pedestrian crashes and the variables that are typical of those cities.

3.2 Methods for risk classification at the tactical level

Risk classification should be based on in-depth analyses of pedestrian fatal and injury crashes and risk levels adopted for selected risk measures. Since 2006 Poland has been a member of EuroRAP (European Road Assessment Programme). Building on the programme methodology [15], the risk for pedestrians is classified on a regular basis using crash data. The results are mapped on risk maps available to the public on-line. Risk levels are presented using a clear five band scale of colours: green meaning the lowest risk (and the best safety) with black showing the highest risk and the poorest safety. By using this method risk can be classified at country and region level; we can select areas (region, county), road sections and junctions where the risk for a pedestrian of being involved in a fatal or injury crash is the highest.

To identify pedestrian societal risk, we use pedestrian fatalities and serious injuries as a general risk measure and the demographic rate or density of fatal and serious injury pedestrian crashes as a normalised measure. The analysis is conducted for a 3 year period. This is to avoid the effects of periodical variations or varying road crash numbers due to e.g. the weather (long and snowy winter) and road improvement which may affect the above measures. The boundaries of safety measures are selected based on analyses of areas (regions and counties) and road networks (national, regional and local). The approach used here is probabilistic and engineering (expert) [3]. Risk classification may be done at the regional and county level and for national and regional roads. An example is given in Fig. 4, where the demographic rate of serious accidents is measured as the number of crashes per population and density of serious accidents is measured by comparing the number of crashes to the length of road section.

The method can be used both at the strategic and tactical level of pedestrian safety management. Risk classification of areas and roads can be helpful for authorities (central, regional) when they take decisions at the strategic, tactical or operational level and for road authorities and local authorities when they select pedestrian safety improvement measures and where these should be located. The results of the classification can be helpful with promoting safety assessment, conducting research, planning and developing safety strategies and programmes and implementing effective actions where they are most needed. The method helps select: areas (region, county), long road sections (on national and regional roads), short sections of streets and junctions (in cities) that have the highest risk for pedestrians to become involved in a road fatal or injury crash.

The results of risk classification identify areas/road sections where pedestrian risk is the highest (red and black) and require an intervention to reduce or eliminate the hazard. Following the analyses, risk can be monitored in the years to come to keep track of any changes in pedestrian safety.

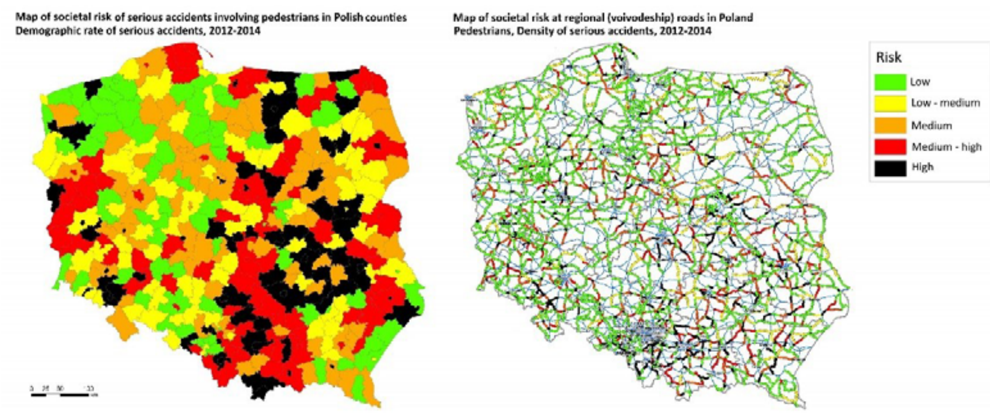

Fig. 4. Pedestrian risk classification based on EuroRAP methodology.

3.3 Methods for identifying hazardous sites at the operational level

Risk assessment at the operational level is supported with identification of hazardous sites. Methods for identifying hazardous sites can be used as a tool for supporting pedestrian safety management. One such method is the "stepping kilometre", presented in [16]. In the method roads are analysed to identify sections where the risk of a road crash is the highest. A one kilometre section is selected on a road with the highest fatal and injury crashes or the highest casualty density. The analysis is conducted in 5 steps: (step 1) determining the first kilometre of a road section 0.0 + 1.0 km and dividing it into 100 m long sections; (step 2) adding up fatal/ injury crashes and casualties for the first ten 100 m long sections; (step 3) shifting by a 100 m and adding up fatal/ injury crashes and casualties on 100 m long sections from 1 to 11, next from 2 to 12, etc., until the final 100 m section; (step 4) summarising the fatal/ injury crashes and casualty numbers for all sections on 1 km; (step 5) analysis of the data will help to select the section with the highest number of fatal/ injury crashes and casualties for the whole road.

Figure 5 shows an example of how the method is used: a road section of 7 km length is analysed according to the above 5-step methodology. The analysis helped to identify three sections (marked on the diagram), where the number of fatal and injury crashes exceeded the critical value, that require an intervention to improve road safety.

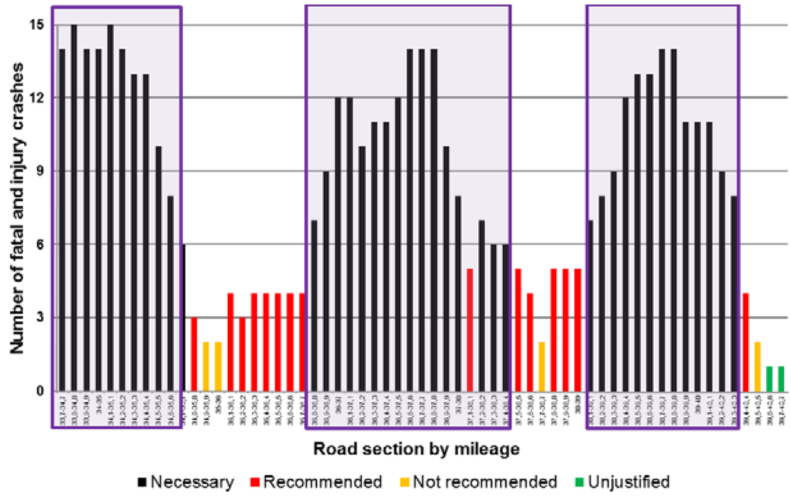

Fig. 5. Identifying hazardous sites with "stepping kilometre" method [16].

The method can be used to identify and assess risk on sites where pedestrian risk is particularly high. This can be the basis for recommendations on measures to be implemented to eliminate or reduce the risk for pedestrians.

The tool can support the pedestrian safety management process at the operational level, in particular. It helps to analyse, asses and classify risk for further risk responses using engineering and expert solutions and by formulating guidelines and recommendations for road authorities.

4 Conclusions

Pedestrian safety in many developing countries continues to be one of the most important and unsolved problems of road safety. This is why efforts in these countries to improve pedestrian safety are vital and will help meet the European Commission's road safety recommendations. Poland is one of the countries where pedestrian safety is a noticeable issue. With no comprehensive approach to pedestrian safety or tried and tested and effective pedestrian safety tools, the country needs a systemic approach to pedestrian safety management across all levels. This is to include an exact identification of pedestrian risks, selecting effective and economically efficient interventions and a systematic monitoring of risk and communicating it. Based on risk, the pedestrian safety management method proposed in the paper offers a tool for a thorough analysis and risk assessment and subsequently a selection of effective risk response measures. The method, however, must be accompanied by tools to support effective and efficient pedestrian safety management. The relevant tools for the strategic, tactical and operational level are presented in the paper. Some are already applied in practice while others require further research.

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