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Tools for road infrastructure safety management – Polish experiences

Kazimierz Jamroz[a], Marcin Budzyński[a], Wojciech Kustra[a], Lech Michalski[a]
Stanislaw Gaca[b]

[a]*Gdansk University of Technology, Civil & Environmental Engineering Faculty, Highway Engineering Department, 11 Narutowicza str, 80-232 Gdansk,*
[b]*Cracow University of Technology, Civil Engineering Faculty, Road Construction & Traffic Engineering Department 24 Warszawska str, 30-962 Cracow*

Abstract

The objective of road safety infrastructure management is to ensure that when roads are planned, designed, built and used road risks can be systematically identified, assessed, removed and mitigated. There are a number of approaches to road safety management. European Union Directive 2008/96/EC requires EU member states to use four basic tools of road safety infrastructure management. An overview of the methods in these countries shows a variety of approaches to how these tools are used in practice. The paper presents a systematics of these tools and a concept of how they could be developed in Poland. It looks at the life cycle of a road structure and the requirements of risk management processes. The paper focuses on elements of scientific support to help build the necessary tools. To help with assessing the impact of a road project on the safety of related roads, a method was developed for long-term forecasts of accidents and accident victims and accident cost estimation as well as a risk classification to identify risks that are not acceptable risks. With regard to road safety audits and road safety inspection, a set of principles was developed to identify risks and the basic classification of errors and omissions. In the case of road network safety management, measures of individual and societal risk were selected. A method for classifying dangerous road sections was developed as well. An estimation is given of the consequences and effects of applying the tools of road safety management on the network of national roads in Poland until 2020.

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Keywords: road safety management, risk management, effectiveness of management tools

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1. Introduction

Road transport safety is significantly less developed than that of rail, water and air transport. The average individual risk of being a fatality in relation to the distance covered is thirty times higher in road transport that in the other modes. This is mainly because the different modes have a different approach to safety management and to the use of risk management methods and tools. Regardless of the type of transport, the key to successful safety management is a detailed risk analysis, thorough risk assessment, quantitative risk acceptance criteria, methods for selecting effective measures and on-going monitoring of the risks and communicating them. In recent years Poland has had one of the European Union's highest road death numbers. In 2012 there were 3574 fatalities on Polish roads with 45,800 injuries*. Protecting road users from the risk of injury and death should be given top priority. While Poland's national and regional road safety programmes address this problem and are instrumental in systematically reducing the number of casualties, the effects are far from the expectations. Modern approaches to safety focus on three integrated elements: infrastructure measures, safety management and safety culture (Burman and Evans, 2008). Due to its complexity, the process of road safety management requires modern tools to help with identifying road user risks, assess and evaluate the safety of road infrastructure and select effective measures to improve road safety. One possible tool for tackling this problem is the risk-based method for road infrastructure safety management. The objective of road infrastructure safety management is to apply procedures that will ensure that when road infrastructure is planned, designed, built and used road risks can be systematically identified, assessed for road user risks, removed and mitigated in terms of injuries, deaths and the economic costs of road accidents (Jamroz, 2011).

Road safety improvement is also a key objective of the European Union's transport policy. Its aim is to halve fatalities within the next decade and achieve Vision ZERO by the mid 21st century. One of the most important documents, which determines directions of road safety actions is EU Directive no. 2008/96/WE of 19 November 2008 on road infrastructure safety management (European Parliament, 2008). Many surveys and studies preceded development of the Directive assumptions, issues or outlines. One of the most important work, lying foundations of the future Directive, were surveys conducted by RIPCORD-ISEREST in the Sixth Framework Programme for Research and Technological Development in 2005-2008 (Ripcord-Iserest, 2005).

In other works or documents preceding the Directive implementation, we can also find issues connected to road safety management (Eenink et al., 2005; Elvik and Vaa, 2004; PIARC Technical Committee 18, 2004a, 2004b).

The Directive recommends that member states should use tools for managing road safety such as: road safety impact assessment (RIA), road safety audit (RSA), road safety ranking (RSR) and road safety inspection (RSI). While Poland is developing the legislation to implement the Directive, it will only cover national roads that are part of the TEN-T without equipping road authorities with the necessary tools. The specificity of Poland's roads and road user behaviour makes a direct adaptation of European research projects difficult (such as ROSEBUD, SafetyNET, DaCoTa, etc.). In an effort to meet the needs of Poland's road authorities (at the national, regional and local level) the Gdansk University of Technology (Department of Highway Engineering) in cooperation with the Krakow University of Technology (Department of Road Construction and Road Traffic Engineering) have developed several basic tools for managing road infrastructure safety in Poland (Budzynski et al., 2013, 2011). This work has added to the Polish experience of preparing and implementing such tools within the competent road authorities

2. Methodology basis

Safety management methods are developed primarily to help road authorities with decision-making on issues involving road safety, road infrastructure safety and reducing the costs of using road structures in their particular life cycles (Jamroz, 2011). It is agreed that risk management in highway engineering involves a formalised and repetitive procedure which integrates two stages: risk assessment and risk response with regard to the road structure

* *In Poland a road accident injury is when the person injured has had to stay in hospital for at least seven days.*

in question (road network, road sequence, road section, junction, etc.). Poland's road infrastructure safety system was built under the following assumptions:

- the management system and its elements will cover all stages of the life cycle of a road structure,
- road infrastructure safety management is based on the risk management method,
- a variety of methods for identifying risks and sources of risk will be employed

Life cycle of a road structure. Each phase of an engineering structure's life cycle has its unique operational characteristics from when it was planned until it is decommissioned. Deming (Deming, 2000) identifies four life cycles of objects: Plan – Do – Act – Check but in practice complex engineering projects (nuclear plants) and offshore projects are divided into five life cycles: plan (initial concept) – design – build – operate – decommission.

Planning. Planning involves the designation of road corridors in the area under analysis. From the safety management perspective this stage has two important phases: developing a draft concept of the selected road and developing the area's land use plan (city, municipality), a process which happens a few or more than ten years before the road is built. The location of the road (especially of roads of a high technical standard) is key to understanding the traffic flows on the road itself and within its catchment area. The higher the standard of the road, the bigger its range which affects safety in the area quite significantly.

Design. This stage consists of two phases that have important safety implications: the draft design that must be submitted to obtain a siting decision and is made a few years before the actual construction and a detailed design required for the building permission and made not long before the start of construction. The particular elements of the design (draft design, detailed road design with the traffic layout and temporary traffic layout during the construction phase) should be verified and corrected accordingly.

Build. This stage includes two critical phases: construction and commissioning. The first phase should ensure the safety of traffic during construction and how it affects road safety. When preparing the project for commissioning it is important to check whether design requirements have been met and test the location of traffic and traffic safety equipment in real life conditions. As a result of these checks improvements are made to the project to increase safety before it is turned over for use.

Operate. This stage has two important phases: short-term and long-term operation of the road. In the first phase it is important to evaluate how the new road and its elements influence road user behaviour after it has been in use for a short period of time. The second phase involves systematic and periodical road reviews with the aim to identify any risks that may appear on the particular road and remove any defects and shortcomings that may cause risks to road traffic. This is to ensure safety or better safety.

Decommission. At this stage roads are assessed to establish whether they can still be used following improvements or whether they should be closed altogether. When roads are decommissioned the risk to road users is minor which is why the analysis will not cover this phase.

From among these road life cycles, four are critical to how road infrastructure safety is managed: planning, design, build and operation.

Risk management method is a repeatable procedure designed to reduce road risks effectively with special emphasis on reasonable interventions and measures involving road infrastructure. The proposed risk management method has two important phases (Fig. 1) (Jamroz and Smolarek, 2013; Jamroz, 2012, 2011):

- risk assessment,
- risk response.

Risk assessment is a process of analysing and determining acceptable risk based on risk acceptance standards. There are two important elements in the method: risk analysis and risk evaluation.

Risk analysis on a road network involves the systematic collection and use of all available data to understand the risks and sources of those risks on the road, estimation of risk measures and risk hierarchy. A key element of the analysis is selecting a method for forecasting the values of these risk measures, an element of quantitative risk analysis.

Risk evaluation involves checking the particular risk class of a risk as assessed on the road in question (in quantitative or qualitative terms) during risk analysis.

Risk response is the next important stage of risk management. It is a set of methods, tools, procedures and processes designed to change potential risk on the road under analysis. The key to risk management is the ability to decide which types of risk should be avoided, transferred, reduced and accepted. Responding to risk includes three important phases of risk management: risk treatment, risk monitoring and communicating risk.

Risk treatment means selecting a risk response strategy and selecting the most effective, efficient and feasible measures (interventions) to push the risks below the level of acceptable risk.

Risk monitoring is a process which comprises: checking for new sources of risk, periodical determination of risk measures' value and keeping track of changing risk acceptance levels, checking the operation of measures for reducing excessive risk and checking whether risk management procedures are followed.

Communicating risk involves the transfer and exchange of information between a road manager and road user. Communicating risks is a particularly important element of risk management. It is a two-way process which involves keeping partners and the public informed about risk assessment, obtaining the feedback from road users and understanding their concerns, explaining any uncertainties and involving partners and communities in the decision-making process.

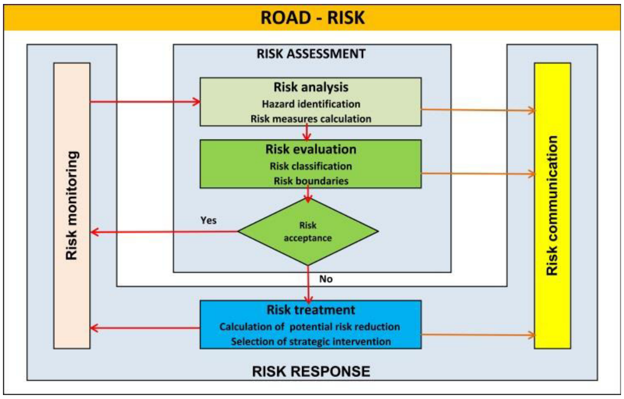

Fig. 1. Diagram of the risk management method (Jamroz and Smolarek, 2013; Jamroz, 2011)

Methods for identifying risks and sources of risk. The practice of road safety and medicine both use two types of therapy: tackling the symptoms or causes.

Symptom therapy (ex-post) identifies risks and their sources by analysing road accidents and their consequences.

Cause therapy (ex-ante) identifies risks and sources of risk based on on-site inspections (in the case of an existing road) or design audits (when a road is planned or designed) and by analysing anticipated (forecasted) road accidents and their consequences.

3. Road Safety Impact Assessment method (RIA)

The objective of the Road Safety Impact Assessment is to determine the impacts of different road variants on the road safety of other roads within a network affected by the planned road (Appleton, 2009; Basile and Persia, 2012; Brannolte and Münch, 2009; Gerlach, 2012). The results of this analysis should be included in the multi-criteria analysis (together with other criteria, i.e. technical, economic and environmental criteria) when assessing the variants of the new road. The road safety impact assessment is made at the planning stage along with the steps included in the first phase of risk management, i.e. risk assessment using elements of causal therapy.

The road safety impact assessment should also provide a basis for rejecting road variants which do not meet the basic road safety standards (Budzynski et al., 2011). The report on the assessment includes:

- a ranking of the analysed variants of the project identifying the best variant for road safety,
- a list and explanations as to why specific variants do not meet risk acceptability standards,
- elements of roads adjacent to the planned road which may be affected by deteriorated safety due to increased traffic volumes (e.g. on access roads to new interchanges or junctions).

The key research problems in the development of the method included:

- determining the impact of the new road on the safety within the road network,
- forecasting the measures of safety on the road network under analysis,
- classifying risk acceptability.

The method for determining the impact of the planned road on the safety within the network of related roads is designed to estimate selected measures of road safety for the particular variants in the area under analysis. The following are the basic measures of road safety:

- societal: number of accidents A, number of injuries I and number of killed K,
- economic: sum of accident costs CA.

When estimating safety measures for the particular road variants and the baseline variant we need to identify the area under analysis, divide the existing and planned road network into heterogeneous sections (in terms of their geometry and roadside environment), estimate exiting and forecasted traffic on these road sections and collect data about geometric and roadside characteristics of these sections. To assess safety, the analysis should cover a period of at least 20 years of operation of the road.

Risk measures are calculated for a specific period using the following relations:

$$A_v = \sum_{i=1}^{n} \sum_{j=1}^{m} (L_{j,i,v} \cdot AD_{j,i,v}) \tag{1}$$

$$I_v = \sum_{i=1}^{n} \sum_{j=1}^{m} (L_{j,i,v} \cdot ID_{j,i,v}) \tag{2}$$

$$K_v = \sum_{i=1}^{n} \sum_{j=1}^{m} (L_{j,i,v} \cdot KD_{j,i,v}) \tag{3}$$

$$AD_v = \sum_{i=1}^{n} (A_{v,i} \cdot AC_{b,i} + I_{v,i} \cdot IC_{b,i} + K_{v,i} \cdot AK_{b,i}) \tag{4}$$

where:

A_v – total number of road accidents on the analysed road network, for variant v (accidents/period of analysis),

I_v – total number of road accident injuries on the analysed road network, for variant v (victims/period of analysis),

K_v – total number of road accident fatalities on the analysed road network, for variant v (victims/period of analysis),

AC_v – total costs of road accidents on the analysed road network, for variant v (m PLN/period of analysis),

$L_{j,i}$ – length of heterogeneous section no. j, in year of analysis i (km),

$AD_{j,i}$ – accident density on heterogeneous section no. j, in year of analysis i (acc./km/year),

$ID_{j,i}$ – road accident injury density on heterogeneous section no. j, in year of analysis i (victims/km/year),

$KD_{j,i}$ – road accident fatality density on heterogeneous section no. j, in year of analysis i (victims/km),
$AC_{b,i}$ – unit (baseline) costs of road accidents on the analysed road network, in year i (m PLN/year),
$IC_{b,i}$ – unit (baseline) costs of road accident injuries on the analysed road network, in year i (m PLN/year),
$KC_{b,i}$ – unit (baseline) costs of road accident fatalities on the analysed road network, in year i (m PLN/year),
v – number of planned road variant,
i – year of analysis,
n – number of years in the period of analysis, n= 20 – 30 years,
j – number of heterogeneous section,
m – number of heterogeneous sections on the analysed road network, m depends on the size of the area affected by the new road.

The method for forecasting safety measures on a road network under analysis is designed to estimate selected road safety measures for the particular variants in the area under analysis including the socio-economic changes, development of the transport network and changes in road traffic. The basic research problem in this method was identifying mathematical models for forecasting three road safety measures in equations 1 – 3, i.e.: accident density AD, injury density ID and density of killed KD also referred to as measures of societal risk. Measures of societal risk are calculated for a specific period separately for single and dual carriageways (Budzynski et al., 2011).

The models were developed using the function of non-linear regression with equation parameters selected from national roads data (600 heterogeneous sections) and accident data for the years 2008 – 2010.

Method for classifying risk on the network of roads under analysis. In assessing the safety standards of a new road, societal risk classification was used set out in the method for identifying high risk sites (RSM). Societal risk is assessed for three year periods over the entire period of the forecast. When the risk is very high and considered unacceptable, the variant is rejected and no longer analysed.

This method has already been used in Poland to carry out more than ten impact assessments for planned sections of express roads to determine their impact on the safety of adjacent roads. More assessments are being conducted by some fifty designers and road authority staff who have been trained by the Authors.

4. Road Safety Audit (RSA)

Poland's earliest attempts at implementing road safety audits go back to 2001-2002 when the first pilot audit guidelines were developed and the staff of national road authorities received audit training. Both universities (Technical University of Gdansk and Krakow) have trained more than 200 road safety auditors within a decade. The auditors carry out systematic audits on the network of national roads (the TEN-T network is compulsory), regional and local roads.

The legal obligation to conduct safety audits was introduced after Poland had implemented the Directive 2008/96/EC and the related legislation in 2012. The obligation applies to the TEN-T roads only.

The road safety audit is carried out at all stages of road life cycles using all stages of risk management with elements of causal therapy.

With more than ten years of experience we can identify two groups of problems that are related to:

- the process of designing roads and the application of safety standards,
- the frequency, accuracy and effectiveness of using road safety audit procedures.

Within the first group of problems, road safety audits show that certain errors recur frequently. They involve faulty designs of cross-sections and alignment, layout maps, junctions and interchanges(Budzynski et al., 2011). The following are the most frequent problems:

- using cross-sections 1x4, 1x6 without a central reservation (especially when cross-sections 2x2, 2x3 could be used),
- structures (poles, guard rails) are placed on narrow pavements (1.5-2.0 m) forcing pedestrians to step onto the road,
- bicycle and pedestrian traffic is not effectively separated in the street cross-section,

- using steep embankments in hazardous sections (horizontal bends, junctions),
- insufficient visibility distance on horizontal and vertical bends (also applies to express roads and on access and exit near noise barriers),
- short distances between junctions; junctions are classified as exits in the design,
- poor surface drainage of the carriageway,
- wrong type of junction, prone to collisions, road marking that is difficult to read,
- interchanges not matching the size and directional distribution of traffic.

These and other errors occur as a result of a complex process. A detailed analysis of auditor reports shows that the main causes of these problems in the Polish road design practice include:

- basic technical regulations do not address road safety issues or address them poorly,
- designers misinterpret data or have incomplete knowledge, lack materials or good practice manuals, etc.,
- "difficult" regulations are ignored with frequent deviations from the technical regulations, designers are overly attached to traditional solutions and designs lack innovation,
- investors and designers treat road safety as a secondary criterion.

The second group of problems stems from the difficulty with ensuring:

- professionals and independent auditors' opinions,
- objective evaluations of road safety solutions in the designs and reasonable recommendations for making the necessary changes in the road design or to an existing road (when preparing to open a road or during early stages of road operation).

Even with auditor training, the objectivity of auditor opinions can only be ensured if it is supported with a broad knowledge base and bespoke methods. At the current stage of road safety audit development in Poland, problems identified by auditors are classified as design errors and defects.

However, more research at the national level and exchange of international experience is required before a full assessment of road safety audit criteria and benefits can be made.

5. Road Safety ranking and management of the road network in operation

Safety ranking of road sections is one of the elements of road safety management on an existing network (Road safety ranking RSR). The main objective of road safety ranking is to identify sections that carry the highest individual risk, i.e. the probability of a fatal road accident is the highest, and sections that carry the highest societal risk and offer the strongest potential for reducing accident costs as a result of treatment undertaken by road managers.

The indirect objectives of RSR are to:

- systematically assess road safety on an existing road network,
- identify and rank sections that carry the highest risk of a fatal accident and the highest accident costs,
- identify and rank sections that have the highest accident cost density and sections that have the strongest potential for reducing road accident costs,
- build a basis for selecting sections of existing roads where road safety measures are a priority offering the biggest returns in terms of effectiveness and efficiency.

Hazardous road sections are classified when roads are in operation by carrying out measures which form part of the first phase of risk management, i.e. risk assessment using elements of symptom therapy and risk communication.

As set out in the Directive and Poland's legal regulations road safety ranking is conducted in a systematic (at least every three years) and periodical safety assessment of the existing road network. For the purposes of safety ranking the existing road network is divided into heterogeneous sections, 2 – 10 km long. The sections should have similar parameters: road class, number of traffic lanes, type of area (urban, rural) and similar traffic volumes (Budzynski et al., 2013).

The data required for safety analysis and assessment (traffic, road accidents and unit costs of road accidents) should cover a period of the last three years (preceding the period of analysis). Road sections are ranked for accident concentration based on individual risk. Because urban and non-urban areas have different accident severity rates, two measures are used:

- concentration of fatal accidents (CK) focusing in particular on the consequences and severity of accidents on non-urban roads,
- concentration of accident costs (CCA) focusing in particular on the consequences and costs of accidents on urban roads.

Fatality concentration is studied for three categories of road traffic: all road users, vulnerable road users (pedestrians and cyclists) and motorcyclists.

Road sections are ranked for their safety on the basis of societal risk. Because a distinction is made between sections that have the highest accident costs and those that have the strongest potential for reducing accident costs, two measures are used:

- density of road accident costs (AD) which includes the total costs of road accidents on sections of roads,
- potential for road accident cost reduction (PCAR) which includes the potential for road safety treatment.

There is an interesting principle of calculating the potential for reducing road accident costs (PCAR):

$$PCAR_j = CAD_j - CAD_{b,j,l} \tag{5}$$

$$CAD_{b,j,l} = \frac{VKT_j * \mathrm{CCA}_{b,1}}{L_j} \tag{6}$$

where:

$PCAR_j$ – potential for reducing road accident costs on section j, for l type of road with a high road safety standard, (m PLN/km/3 years)

CAD_j – density of accident costs on road section j (m PLN/1 km/3 years),

$CAD_{b,j,l}$ – baseline density of accident costs on road section j, when standard interventions are used for k type of road (m PLN/1 km/3 years),

$CCA_{b,l}$– baseline concentration of normalised accident costs on the road section when high road safety standard interventions are used for k type of road (m PLN/1m vkt),

VKT_j – kilometres travelled on road section j (1m vkt/3 years)

L_j – length of road section (km)

k – class of road, k = 1 – (motorways and express roads), k = 2 – (main roads).

The road safety ranking is based on a methodology used in the EuroRAP Programme (EuroRAP, n.d.). The accident cost reduction ranking identifies sections with the strongest potential for accident and casualty reduction if the section is treated to high road safety standards. The proposed safety ranking identifies five classes of accident cost reduction potential (A, B, C, D, E). The division into the classes is based on the distribution of accident cost density on national roads for the years 2008 – 2010 and fixed accident prices in 2011 (Budzynski et al., 2013). Table 1 shows the classification. With the last class (E) covering more than 10% of sections with the highest potential for accident cost reduction, it will form the basis for identifying a list of sections where interventions are expected to be most effective.

6. Road safety inspection

The procedures of road safety inspection (RSI) on Poland's national roads identify three types of inspection: overall (IO), detailed (ID) and special (IS) inspection. Overall inspection (IO) applies to the entire network of national roads and is conducted regularly and cyclically. Detailed inspection (ID) covers selected sections and spots identified in safety ranking (RSM) and in overall inspection (IO). Special inspection is also carried out at night-time (NK) on hotspot sections where accidents occur from dusk till dawn (regarding sections and locations referred for detailed inspection). It is also conducted in areas of road works (RDK) which continue for more than 24 h. Overall inspections are cyclical while detailed and special inspections are carried out on E risk level sections or whenever needed.

Table 1. Classification of road sections for their potential to reduce road accident costs (societal risk)

Class of potential effectiveness of interventions	Expected road accident cost reduction	PCAR	
		from	too
A	Very low	0,00	0,22
B	Low	0,22	0,45
C	Medium	0,45	0,75
D	High	0,75	1,20
E	Very high	> 1,20	

Road safety inspection looks at all structures of importance for road safety and all phenomena occurring on roads and in the safety zone, and in particular:

- geometry of roadway, pavements, cycle paths, pavements on road sections, shoulders, batters, ditches, culvert walls and retaining walls,
- geometry of roadway, pavements, cycle paths within junctions and interchanges,
- horizontal and vertical signage, traffic control, traffic management,
- lateral obstacles (trees, shrubs), barriers, rails, fencing and other road safety furniture,
- road frame drainage (central reservation, kerbside drainage, batter drainage),
- level crossings, bridges, viaducts, tunnels, animal passes,
- visibility in areas of exits, junctions, service areas, interchanges, visibility in between interchanges, road lighting,
- other elements of infrastructure in the safety zone (e.g. advertising, fencing, noise barriers, etc.).

Once identified, a risk must either be removed or mitigated by reducing the potential risk or implementing measures to protect users against the risk. This forms the basis for further steps designed to solve the problem. As a first step four classes of defects are defined ranging from A – low risk to D – very high risk. The classification should be based on objective measures for ranking the risks and identifying their respective risk classes and specific interventions. Road safety inspections are carried out on roads in operation and include measures that are part of all risk management phases. Risks are identified using elements of causal therapy.

Road safety inspection guidelines for national roads were developed on the basis of studies and pilot projects. More than 150 inspectors have been trained. This spring the inspectors will be carrying out road safety inspections on the hotspot sections of national roads identified in the safety ranking. There are plans to implement road safety inspections on networks of regional and local roads.

At present work is under way to adopt objective measures for assessing road risks. The effects of speed and traffic volume on risk classes must be identified. The investigation covers a variety of areas: non-urban, peripheral urban areas, sections of transit roads passing through small towns and city centres. In addition, sections of fast traffic roads are also investigated. Once completed, the investigation will help create a tool for objective risk rankings when studying risks on the road and roadside.

7. Conclusion

A well organised system of road safety equipped with the right structures and procedures can help to reduce the risk of death and injury in road traffic. If properly applied, each of the above tools for road safety management can help to reduce road accident victims. Initial analyses show that the particular tools for road infrastructure safety management could reduce the number of casualties:

- road safety impact assessment (RIA) – 10 – 25%,
- road safety audit (RSA) – 5 – 20%,
- road safety management (periodic) (RSM) – 5 – 15%,
- road safety inspection (systematic) (RSI) – 1 – 20%.

Effectiveness is higher on roads which did not go through road safety management procedures at the earlier stages (road safety impact assessment, road safety audit or road safety management).

While TEN-T roads (4.8 thou. km) in Poland have the highest safety standards, they still generate almost 8% of all road accidents, 9% of injuries and 15% of all fatalities and 9% of accident costs.

If properly managed, road safety interventions on Poland's TEN-T roads over the next decade could see a reduction in fatalities by 30 – 40% i.e. by 2400 people killed, 25,000 injuries and PLN 10 billion less in accident costs.

Over a period of ten years the costs of the procedures and money saved as a result of fewer accidents could produce an effect of 195:1 which means that each zloty spent on the operation of the road safety management system will generate PLN 195 saved on accident costs.

An initial estimation of the number of TEN-T users saved from death depending on the type of tool for road infrastructure safety management shows that each of the tools has a fairly significant impact on fatality reduction on Poland's TEN-T roads.

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