Trees in the Roadside as a Factor of Poland's Road Safety

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Abstract

Roadside-related crashes occur when vehicles run off the road. The majority of the crashes have severe outcomes, especially when an object is hit (tree, pole, supports, front wall of a culvert, barrier). These accidents represent app. 19% of all of Poland's road deaths. The following types of roadside-related crashes were selected (based on SEWIK, a police database): hitting a tree (the main hazard), hitting a barrier, hitting a utility pole or sign, vehicle roll-over on the roadside, vehicle roll-over on a slope and vehicle roll-over in a ditch. Understanding the effects of these roadside factors requires in-depth research. Sections of national roads were used to build models of selected road and traffic factors and their effects on road safety. In addition, risk mapping was made for national and regional roads highlighting selected problems, including the roadside.

Background

A vehicle runs off the road when it loses stability or changes its direction rapidly (a result of excessive speed, loss of wheel grip, etc.). While the vehicle will occasionally return to the road, there are other secondary and very dangerous consequences as well: vehicle roll-over, driving into a ditch, hitting a slope or a roadside object such as striking a safety barrier, hitting a tree, utility pole or road sign (Budzyński & Jamroz 2009).

The risk of becoming involved in an accident is the result of a malfunctioning element of the transport system (man – vehicle – road – environment). The road and its traffic layout and safety equipment have a critical impact on road user safety (Jamroz, 2011). This gives infrastructural work a priority in road safety programmes and strategies at the global (WHO, 2011), European (EC, 2010) and national level (MIR, 2013) Run-off-road accidents continue to be one of the biggest problems of road safety. They lead to secondary collisions when the vehicle rolls over or hits a roadside object (Jamroz et al., 2015). This type of accident represents more than 25% of rural accidents and nearly 20% of all road deaths in Poland. The likelihood and consequences of run-off-road accidents may be reduced where road measures are used to improve safety (Budzynski& Jamroz, 2009).

The problem is also addressed in the National Road Safety Programme until 2020 (MIR, 2013) with one of its priorities in the Safe Road pillar setting a run-off-road accident reduction target. This is to be achieved by developing and implementing the concept of "forgiving roads", i.e. roads with no side obstacles causing a hazard or, if there are obstacles fitting them with passive safety devices. In addition, road signage should be comprehensible and user-friendly. Run-off-road accidents, which include hitting a tree, pole, sign or safety barrier, represent about 10% of all accidents in Poland and more than 19% of road deaths. On a national scale, these accidents are some of the most frequent. A detailed analysis shows that when a vehicle leaves the road it usually hits a tree (nearly 7% of all road accidents in Poland). Hitting a barrier, utility pole or sign is less frequent (Jamroz, 2011; WHO, 2011; MIR, 2013). Roadside trees are one of the most serious problems of road safety. One way to solve it is to use safety barriers. Barriers are used to reduce the consequences of an accident or collision (as opposed to striking a tree in a head-on collision). To that end barriers must be designed and built to respond adequately when struck by a car.

The main problem related to the roadside is trees on the edge of the road. The risks are particularly high in north-west Poland with many of the roads lined up with trees, a legacy from the past.

This may have dire consequences as could be seen in the tragic accident near Gdansk in 1994 when a bus hit a tree leaving 33 people injured and 30 killed.

With no legal definition of the clear zone in Polish regulations, attempts to remove roadside trees lead to major conflicts with environmental stakeholders. Documents and regulations are urgently needed to improve roadside safety. This, however, will take time and more research. This is why a compromise should be sought between the safety of road users and protection of the natural environment and the aesthetics of the road experience Rather than just cut the trees, other road safety measures should be used where possible to treat the hazardous spots by securing trees and obstacles and through speed management.

Analysis of statistics

Between 2013 and 2015 there were 16,500 accidents related to the roadside (11% of all accidents in that period). The accidents involved 20,700 people injured (16%), including 6,400 seriously injured (16%) and 2,100 people killed (24%). Figure 1 shows the types of roadside-related accidents across the country. As much as 73% of fatalities are caused by hitting a tree. The severity of accidents was analysed for the different types of run-off-road accidents (the number of fatalities per 100 accidents). The following are the results: hitting a barrier – 10, hitting a tree - 23, hitting a sign or utility pole – 9, rollover - 7. As the figures show, run-off-road accidents are clearly most severe when they involve hitting a tree.

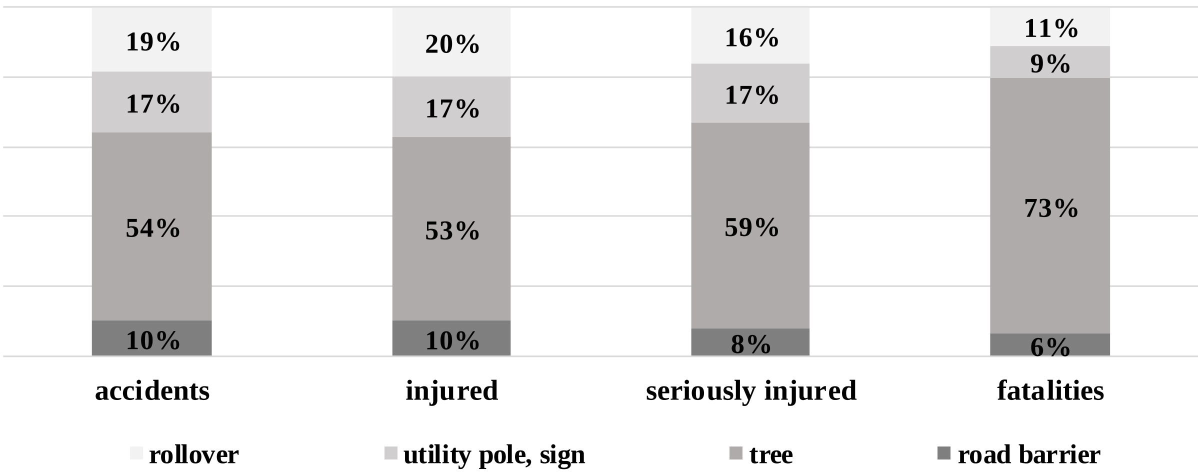

Figure 1 Types of accidents involving the roadside in Poland

The next analysis looked at roadside accidents by road category (national, regional and others – county and municipal roads). Run-off-road accidents are most common on regional roads (15%), followed by national roads at 9% and other roads at 10%. As regards fatalities, the majority occurred on other roads at 24%, regional roads at 22% and national roads at 11%. Safety of national roads is much better than in the other categories. This is because more investments are made to upgrade these roads and the removal of roadside trees is easier.

Roadside accidents were also analysed for regional distribution. It was found that in the years 2013 - 2015 (Fig. 2): the highest share of fatalities was recorded in the regions of Zachodnio-Pomorskie - 34% of all fatalities, Warminsko-Mazurskie - 33%, Pomorskie - 27%, Lubuskie - 27%.

Analysis of roadside accident location confirmed that the north-west and north-east of Poland is at particular risk with the regions of Warminsko-Mazurskie, Zachodnio-Pomorskie, Lubuskie and

Pomorskie clearly having the worst record (the main reason - numerous sections of roads with trees at the edge of the road). New measures are required to reduce the hazards posed by dangerous roadside environments.

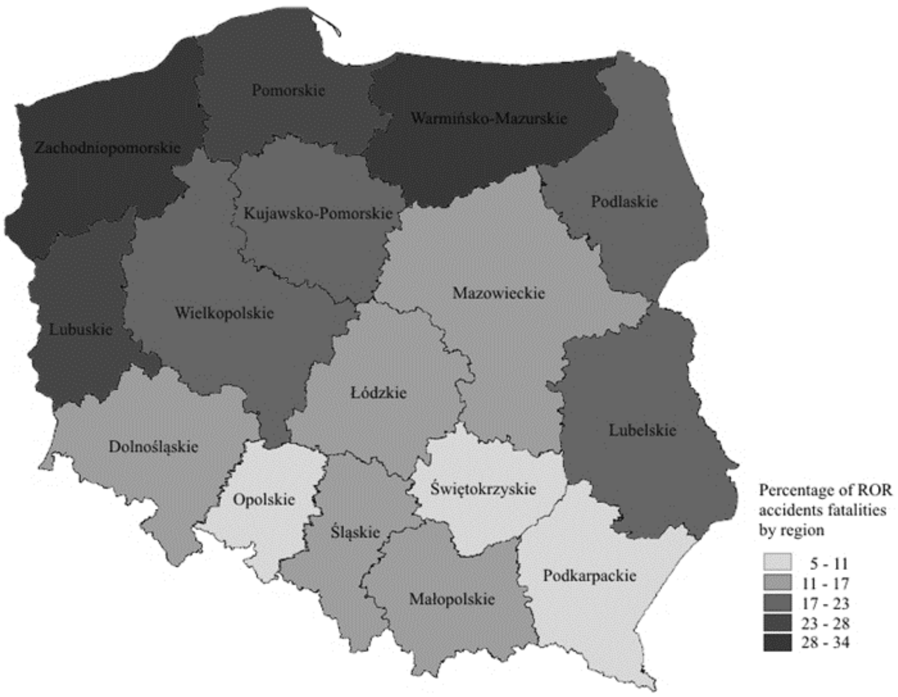

Figure 2 Roadside-related accidents and victims by region

Identifying roadside hazards

A number of in-the-field tests were conducted looking at road infrastructure and its safety. Based on the findings, a number of elements were identified which present a potential roadside hazard to road users. In 2013 a road safety inspection method was developed and implemented. The development of the Polish method took into account the experience of other countries (RSI, 2012; Cafiso et al., 2006). Selected sources of hazards were illustrated with photographic documentation (Fig. 3). Potential reasons for "high risk" roadside areas identified include:

- trees close to the edge of the road (up to 3 metres away from the edge of the carriageway the risk is the highest, especially in the area of bends in horizontal alignment, junctions and exits),
- other green restricting visibility,
- elements of infrastructure which are unyielding (concrete or wooden poles, masts, etc.),
- supports of civil engineering objects too close to the edge of the road, unsecured (e.g. bridge supports),
- drainage facilities – vertical concrete front walls of culverts,
- steep embankments,
- poor technical condition of shoulders,

- inadequately terminated, too short, wrong operating width and damaged road barriers.

As well as being the direct cause of an accident, these sources of hazards cause other types of accidents because of where they are. This includes head-on collisions if there are structures within the road, hitting a pedestrian or bicyclist because there is no space for the vehicle to use beyond the carriageway. When these types of accidents are reported, the statistics does not take account of the roadside as a cause or circumstance (e.g. no trees were hit but it was the trees that restricted visibility and eventually led to the accident). As a result, roadside conditions are underreported in road accident databases.

Figure 3 Examples of roadside hazards

Methods for studying the effects of roadside features on road safety

A study of available literature shows that some researchers were trying to establish the effects of selected road parameters (roadway width, type and width of shoulder, roadside trees and road signs), road structures (bridges, culverts, road signs), roadside obstacles (trees, utility poles) and road devices (safety barriers and fencing) on run-off-road accidents. The results of the research were used to model and simulate the effects of different combinations of road geometry parameters and traffic parameters on the frequency and consequences of accidents. Building on the models preventive measures were developed. It was demonstrated that accident frequency can be significantly reduced by widening traffic lanes and shoulders, widening the central reservation, widening the road on approaching a bridge, moving and removing hazardous road objects, reducing the steepness of slopes and ditch walls and using safety barriers and other safety systems (Lee & Mannering 1999).

The most recent research focuses on “forgiving roads” which give priority to roadside clearance zones. Using the results of fieldwork, mathematical modelling and computer simulation, recommendations were formulated for the width of the clearance zone and the distance between the road and height of safety barriers (Jamieson et al. 2011).

There is research and work on new standards, guidelines and good practice focusing on trees that are too close to the road, faulty utility poles or road sign structures, poorly designed or poorly built systems of safety barriers. The models have indicated the importance of protecting vehicles from crashes with rigid poles and tree stumps because such crashes are linked with higher severities and fatalities. (Holdridge at al. 2005).

With technical policy, guidelines and practice not based on recent road safety science, roadside environments are posing a serious danger to safety. As we know from a number of studies looking at how specific road factors affect roadside safety, the roadside environment and its components are critical (trees, vegetation, shoulders, embankments, drainage ditches, poles, signs, engineering objects, etc., as per Budzynski & Kustra, 2012; AASHTO, 2010; Lee & Mannering, 1999; Viner, 1995; Zegeer & Forrest, 1995; Jurewicz & Troutbeck, 2012; Moon & Mihailidis, 2013). There is a need to develop more precise road safety analysis tools which can inform revision of technical policy, guidelines and best practice.

An accident involving a vehicle crashing into unprotected roadside objects could probably be avoided or mitigated. When new roads are built, designers of safety systems should ensure that all roadside hazards are sufficiently dealt with. Unfortunately, safety has only become an issue for new roads. Since 2010 each system of safety barriers must be tested and hold a compliance certificate as well as a declaration of performance. The question, however, should be – what is the effect of hazardous roadside devices and objects for the different road classes on Poland’s road safety?

All the examples above were identified when checks were conducted on Poland’s national and regional roads. Sadly, there are many more examples. The above accident statistics are a consequence of what is a hazardous roadside environment.

Roadside risk management

Roadside safety management can be delivered at three levels: strategic (national), tactical (regional) and operational (local). It is based on the Directive of the European Parliament 2008/96/EC (Directive, 2008) and is part of road safety management in the broad sense (Jamroz, 2011). The article focuses on tactical level management because a similar level was used to build the accident density model as highlighted above.

Tactical risk management occurs primarily when roads and road objects are designed and operated. This is delivered by regional authorities and regional road authorities. The main sources of hazard (factors) that contribute to the severity of run-off-road accidents and require tactical level action include: the region of the country; as already presented, these problems occur in the north and west of the country, as an example in the region of Pomorskie sections of roads with trees that are less than 1.5 m away from the road occur on 20% of national roads, 40% of regional roads and 65% of local roads; road category - roadsides are safer (fewer obstacles, more safety measures) on national roads of higher technical class; type of road section (straight section or horizontal curve), limited visibility, especially at night-time.

The main actions at the tactical level include the design, construction and operation of roads to take account of high risk road sections, (risk maps prepared in the EuroRAP project - Fig.4, are very helpful with that), removing hazardous objects: felling trees, rearranging the objects or relocating the road away from the objects, securing hazardous objects by using safety barriers and other structures, speed management and hazard notification and implementing roadside safety standards. A major problem to be addressed at this level of management is obtaining permits to fell roadside trees (from Regional Directorates for Environmental Protection) which pose a risk to road users.

Individual risk was used to draw up risk maps of regional roads' roadsides. Individual risk is defined as the probability of a road user becoming involved in a hazardous event or the probability of a consequence to be suffered while using a road network. It refers to the behaviour of a single road user on a road (junction, section in between interchanges). This risk is used to identify road sections which cannot be used safely by individual road users. Road authorities can use it to eliminate hazards by removing or restricting sources of hazard and by informing road users about the most dangerous road sections.

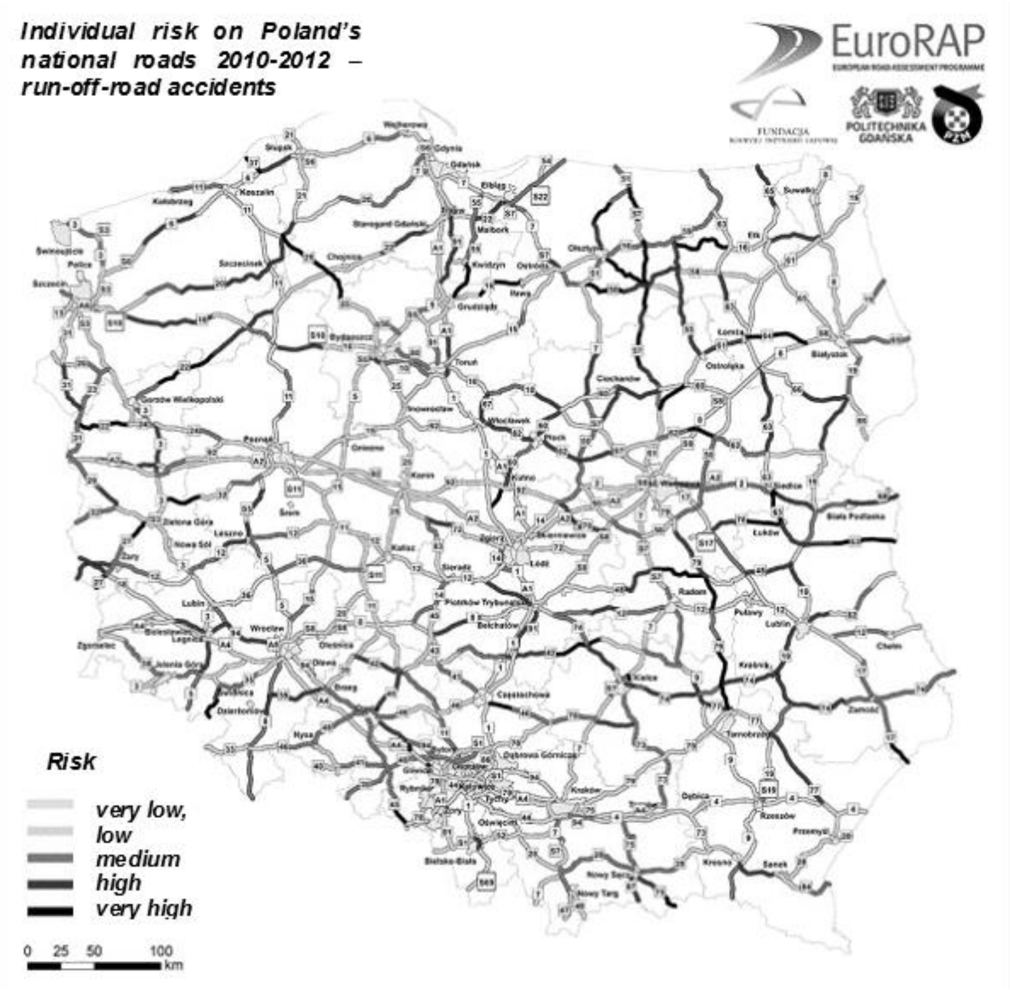

Figure 4 Map of individual risk on national roads – run-off-road accidents Source: eurorap.pl

Modelling the effects of selected roadside elements on road safety

Analyses of models of how roadside elements affect road safety (EASTS, 2005; Elvik, 1994; Karim et al., 2012; RISER, 2006; Petegem & Wegman, 2014; Jurewicz & Steinmetz, 2012) showed that the methodologies and data differ from model to model. Because the models focus on different factors, they each have strengths and weaknesses.

New analytical models for estimation of the frequency of roadside casualty crashes (striking a tree, a barrier, hitting a utility pole or sign) and of their severity were developed to serve as comprehensive roadside safety monitoring tools for Polish conditions.

The assumptions were the following: the model will be used to calculate risk factors and accident severity, the indicators will depend on the number of vehicle kilometres travelled or traffic volumes and analyses will be based on accident data. Additional data will include roadside information and casualty density measures will be used – killed and injured.

This study analysed national roads in the region of Pomorskie. While they only account for 4% of total roads, national roads carry more than 30% of Pomorskie's miles travelled. The first phase of the study was designed to build an inventory of roads and build roadside and accident databases. The next stage was to develop mathematical models to show the correlations between roadside and accidents. All analyses were based on data from the period 2013 – 2015.

The inventory covered all sections of national roads in the region of Pomorskie at the total length of about 970 km. There were separate inventories for the left and right edge of the roadway and the central reservation. Potential roadside hazards were identified (trees, embankments, utility poles, engineering structures) and selected type of barriers (concrete, steel, wire ropes).

The database had about eight thousand records – reference sections 1 – 5 km long. The records contained data about section length, annual average daily traffic flow, number of junctions, exits, and percentage share of sections with barriers, trees, number of signs, utility poles and other road objects.

The basic problem when building the models was data availability and data quality. The first group of indispensable data comprised road accident data. The following were the main groups of problems affecting accident data:

- Lack of a systemic approach to accident data collection. Each of Poland's road safety management levels has its own database with no links or consistency. All databases get their data from SEWIK. As a result, there is a lot of duplication and overlap when data are processed and some data are never used by some organisations.

- Lack of data verification. Accident data are not verified systematically which makes any analysis and use of the data difficult. The police database gets accident locations wrong by quoting a wrong road number, wrong road category, inaccurate accident location and conflicting information regarding accident location.

- Lack of access to additional data. Road safety analyses need additional data regarding road user behaviour such as speed, seatbelt usage, drunk driving or drug driving. Unfortunately, the regional level does not often collect such information.

Availability of data on road elements is another problem. Selected independent variables were not used to build the model, for example the presence and parameters of horizontal curves which have been studied for their effect on safety. Neither was the size of trees and the spacing between them considered. In addition, there should be more classes to specify the distance between trees and the edge of the road. Road width and the technical condition of the road and shoulders were not included either.

To improve the quality of the conclusions and gain more knowledge on how roadside parameters affect safety, the authors are working on extending the available road elements database. Safety measure models will be updated and extended to include the above parameters.

The next part of paper presents the analyses and results of the victim density rate (DV). The objective of the model is to estimate the expected number of victims of accidents on national roads per kilometres of road over a specific period. The victim density model is described with the following formula:

$$DV = \alpha \cdot Q^{\beta_1} \cdot e^{(B^{\beta_2} + S^{\beta_3} + T_1^{\beta_4} + T_2^{\beta_5} + T_3^{\beta_6} + C^{\beta_7} + P_1^{\beta_8} + P_2^{\beta_9} + P_3^{\beta_{10}})} \quad (1)$$

where:

DV - expected number of accident victims per kilometres of road (dependent variable), α - adjustment coefficient, Q - annual average daily traffic (AADT), βj (1,2,…,n) - calculation coefficients, and other independent factors (tab. 1). The model has a determination coefficient (R^2) equal to 0.85. This model is the first attempt to assess the impact of selected roadside factors on road safety in Poland. It is necessary to expand the database and build next models with more variables.

Table 1. Parameter estimates of the crash prediction models of Eq. (1)

Factors	Coefficients		Value	Lower confidence limit	Upper confidence limit
	Adjustment	α	1.14E-07	1.14E-07	1.14E-07
Traffic volume	Q	β_1	0.67	0.31612	1.03195
% of barriers	B	β_2	-3.02	-4.48932	-1.55423
% of embankments	S	β_3	1.73	0.48282	2.99325
% of trees to 3.5m	T_1	β_4	2.85	1.98812	3.71178
% of trees above 3.5m	T_2	β_5	1.25	0.62473	1.87844
% of forests	T_3	β_6	-0.46	-1.46917	0.54344
Road class	C	β_7	8.66	2.70382	14.62712
% of shoulders above 1.5 m	P_1	β_8	-0.63	-0.92808	-0.32719
% of shoulders to 1.5 m	P_2	β_9	-0.46	-1.05439	0.13582
% of soft shoulders	P_3	β_{10}	0.17	-0.75521	1.09778

Results of the study

Victim density was mostly affected by parameters such as the provision of safety barriers, the number of roadside trees (up to 3.5 and above 3.5 m from the edge) and road class. Studies show that victim density declines as the percentage of section with barriers and hard shoulders increases. What is more, once a road is fully equipped with barriers, victims are down to almost to zero (a debatable result which requires an in-depth analysis). Trees that are less than 3.5 m from the edge of the road turned out to be most victim intensive.

Another conclusion from the study is that (Fig. 5 – the effect of trees if up to 3.5 m from the edge (T1) and barriers (B), with the other parameters averaged) the length of sections with roadside trees and the corresponding protection do not in fact have much influence on victim numbers. Nearly identical DV values were obtained for a 20%, 40% and a 60% coverage of roadside trees (T1) were protected with barriers (B). More analyses must be conducted in other Polish regions with more parameters in the models. So far, however, it is clear that safety barriers between the road and trees have a positive effect.

A number of road projects struggle with the choice of the most effective safety measures. Choosing the cheapest option may turn out to be hazardous for road users. The consequences and direct and indirect costs of accidents may exceed the original financial gains. If equipped with the right tools, each of the options can be assessed for its pros and cons (cost and benefit analysis, multiple criteria analysis). Cost analysis of safety barriers is an excellent example. Just as any other road safety equipment, barriers are an additional cost when new roads are built or upgraded. The price, lack of good will on the part of road authorities or lack of knowledge are usually the reasons why safety barriers are frequently ignored. Detailed analyses show that putting in safety barriers may reduce the number (density) of victims compared to the same sections with the same hazards and no safety barriers: it is three times in the case of trees more than 3.5 away from the road edge, five times in the case of embankments and as many as seven times in the case of trees up to 3.5 m from the edge.

In the next study, the location of horizontal curves should be taken into account in the analyzed sections.

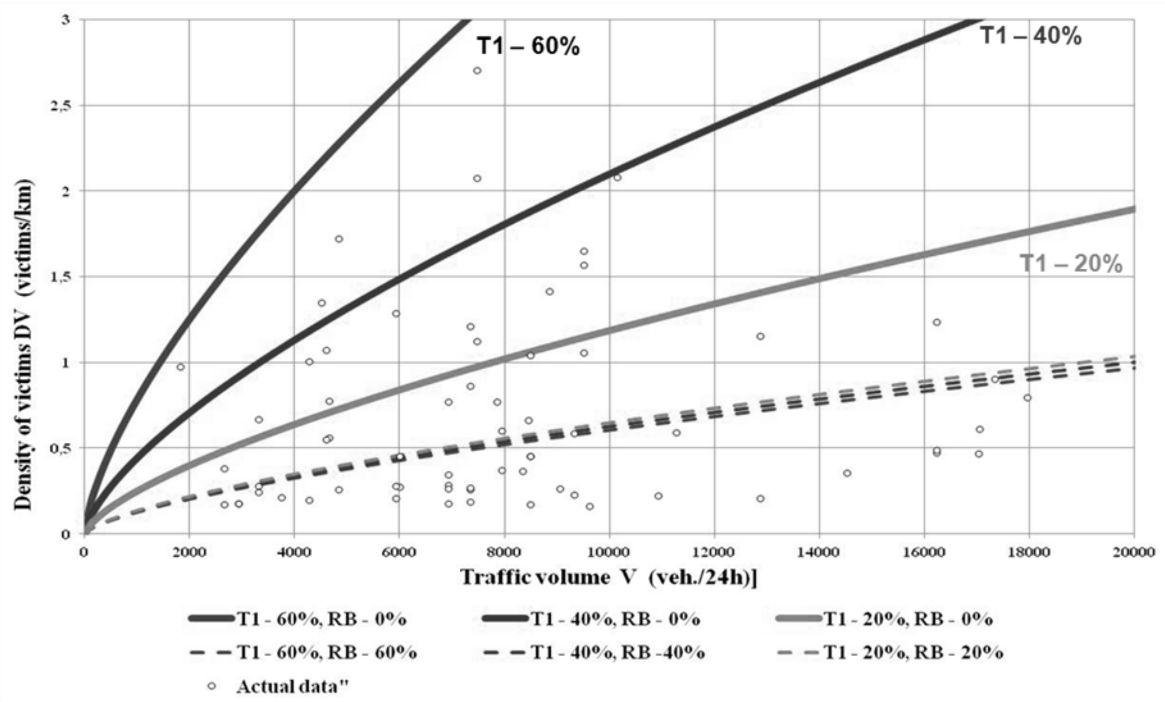

Figure 5. Casualty density in relation to the distance between the tree and road edge and percentage share of barriers

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Summary and Conclusions

Over the last twenty five years more than 20,000 people were killed on Polish roads in run-off-road crashes (of which a clear majority involved hitting a tree). Analyses and studies of roadside hazards offer the following conclusions:

- the main factors that influence the risk of being involved in such a crash are: historic developments, road class, length and element of carriageway, hazardous elements at the edge of carriageway (mainly trees), safety measures in place or lack of safety measures,

- the risk is the highest in the north and east of Poland considering the entire road network, and in the east of Poland in the case of national roads.

- to improve roadside safety we must: identify the hazards on the road network, conduct checks, conduct research (build models of the effects of selected factors on road safety, effectiveness evaluation), implement safety standards, develop guidance and principles for safe roadsides, ensure that there is collaboration between designers, road authorities and environmental organisations and institutions, exchange experience with other countries.
- victim density mostly depended on parameters such as safety barriers, the number of roadside trees (up to 3.5 and above 3.5 m from the edge) and road class, trees located less than 3.5 m from the edge of the road turned out to be most victim intensive; it was clear that safety barriers between the road and trees have a positive effect.

For years roadside environments have been one of the most neglected aspects of road safety efforts in Poland. Clarity is needed on the effects of roadsides on road safety. We must understand the hazards roadsides cause and implement effective solutions.

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