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Effect of the Road Environment on Road Safety in Poland

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Abstract. Run-off-road accidents tend to be very severe because when a vehicle leaves the road, it will often crash into a solid obstacle (tree, pole, supports, front wall of a culvert, barrier). A statistical analysis of the data shows that Poland's main roadside hazard is trees and the severity of vehicles striking a tree in a run-off-road crash. The risks are particularly high in north-west Poland with many of the roads lined up with trees. Because of the existing rural road cross-sections, i.e. having trees directly on road edge followed immediately by drainage ditches, vulnerable road users are prevented from using shoulders and made to use the roadway. With no legal definition of the road safety zone in Polish regulations, attempts to remove roadside trees lead to major conflicts with environmental stakeholders. 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. Accidents that are directly related to the road environment fall into the following categories: hitting a tree, hitting a barrier, hitting a utility pole or sign, vehicle rollover on the shoulder, vehicle rollover on slopes or in ditch. The main consequence of a roadside hazard is not the likelihood of an accident itself but of its severity. Poland's roadside accident severity is primarily the result of poor design or operation of road infrastructure. This comes as a consequence of a lack of regulations or poorly defined regulations and failure to comply with road safety standards. The new analytical model was designed as a combination of the different factors and one that will serve as a comprehensive model. It was assumed that it will describe the effect of the roadside on the number of accidents and their consequences. The design of the model was based on recommendations from analysing other models. The assumptions were the following: the model will be used to calculate risk factors and accident severity, the indicators will depend on number of vehicle kilometres travelled or traffic volumes, analyses will be based on accident data: striking a tree, hitting a barrier, hitting a utility pole or sign. Additional data will include roadside information and casualty density measures will be used – killed and injured.

1. Introduction

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 [1]. This gives infrastructural work a priority in road safety programmes and strategies at the global [2], European [3] and national level [4].

Run-off-road accidents tend to be very severe because when a vehicle leaves the road, it will often crash into a solid obstacle (tree, pole, supports, front wall of a culvert, barrier). The risks are particularly high in north-west Poland with many of the roads lined up with trees. This may have dire consequences as could be seen in the tragic accident near Gdansk in 1994 when a bus hit a tree killing more than 40 people. Because of the existing rural road cross-sections, i.e. having trees directly on road edge followed immediately by drainage ditches, vulnerable road users are prevented from using shoulders and made to use the roadway. With no legal definition of the road safety zone in Polish regulations, attempts to remove roadside trees lead to major conflicts with environmental stakeholders. 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.

Roadside issues are some of the most critical road safety problems. Research has been conducted for a number of years to help identify roadside hazards and ensure effective road user safety measures. Road safety has been on Poland's agenda since 1994, following a World Bank mission which defined the gravity of the problem compared to other countries, mainly in Western Europe. Over the years different road safety programmes emerged. The programmes mainly focussed on the need to change how the roadside should be designed, developed and used, especially on single carriageway non-built-up sections, to reduce the severity of run-off-road crashes [4, 5]. The main consequence of a roadside hazard is not the likelihood of an accident itself but of its severity [6, 7]. Poland's roadside accident severity is primarily the result of poor design or operation of road infrastructure. This comes as a consequence of a lack of regulations or poorly defined regulations and failure to comply with road safety standards. As we know from a number of studies looking at how specific road factors affect safety, the roadside environment and its components (vegetation, shoulders, embankments, drainage ditches, poles, signs, engineering objects, etc.) are very critical [6], [8 - 12].

Roadsides also include barriers. While they stop vehicles from hitting obstacles or going down a roadside slope, they constitute obstacles themselves. If poorly designed in terms of function and structure, barriers may pose a serious hazard. An analysis of crash statistics shows that Poland's main roadside hazard is trees and accident severity when vehicles run off the road and collide with trees. While the other elements are also a source of safety hazard, they are so to a lesser extent.

2. Analysis of statistical data

Between 2013 and 2015, there were 10,422 roadside-related accidents (10% of all accidents within that period). The accidents involved 13,330 injuries (11%), including 4,215 serious injuries (12%) and 1,770 fatalities (19%). With no proper regulations, guidelines or examples of good practice, roadside environments are posing a serious danger to safety. Trees pose a particular hazard. The different types of roadside accidents have caused the following casualties (figure 1):

- accidents: hitting a tree - 5,642 (54%), hitting a pole, sign - 1,771 (17%), roll-over (shoulder, embankment, ditch) - 1,941 (19%), hitting a barrier - 1,068 (10%),
- injured: hitting a tree - 7,047 (53%), hitting a pole, sign - 2,270 (17%), roll-over (shoulder, embankment, ditch) - 2,662 (20%), hitting a barrier - 1,351 (10%),
- serious injuries: hitting a tree - 2,490 (59%), hitting a pole, sign - 704 (17%), roll-over (shoulder, embankment, ditch) - 684 (16%), hitting a barrier - 337 (8%),
- fatalities: hitting a tree - 1,299 (73%), hitting a pole, sign - 239 (10%), roll-over (shoulder, embankment, ditch) - 193 (11%), hitting a barrier - 122 (6%).

The severity of accidents was analysed for the different types of run-off-road accidents (measured as the number of fatalities per 100 accidents). The following are the results: hitting a barrier – 10, hitting a tree - 23, hitting a sign, pole – 9, roll-over - 7. As the figures show run-off-road accidents are clearly most severe when they involve hitting a tree.

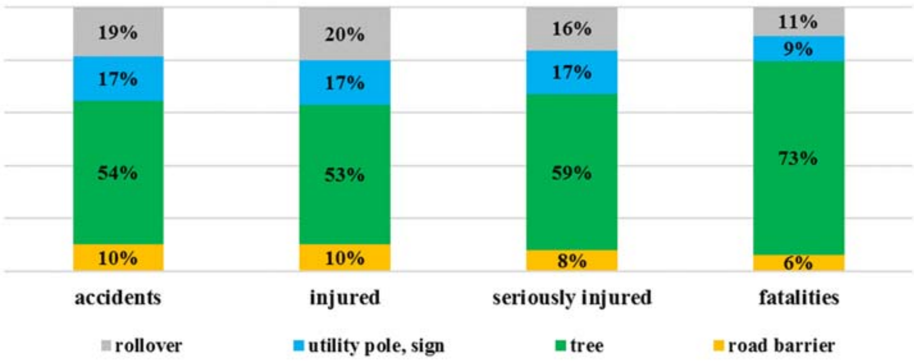

Figure 1 Types of roadside-related accidents

The next analysis looked at roadside accidents by road category. The following categories are applied: national roads, regional roads and other roads (county and municipal). 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 2012 - 2015 (figure 2):

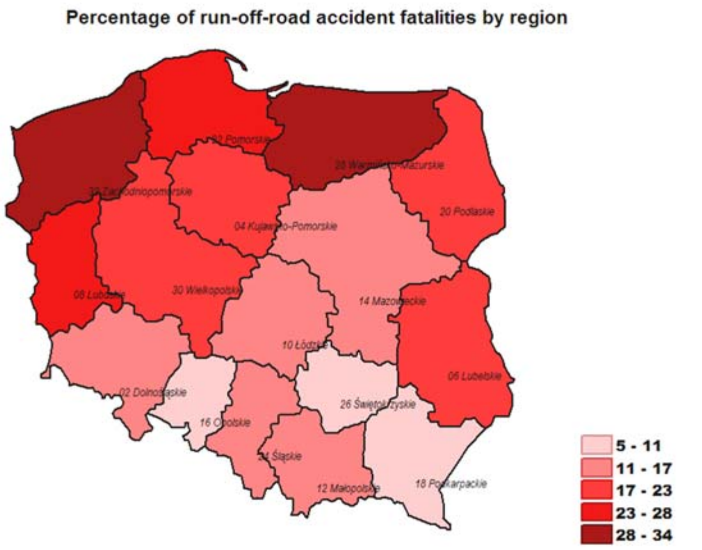

Figure 2 Roadside-related accidents and victims by region

- the highest share of roadside accidents was recorded in the regions of Warminsko-Mazurskie – 1,014 (22% of all accidents), Lubuskie - 502 (20%), Zachodnio-Pomorskie - 656 (15%),
- the highest share of fatalities was recorded in the regions of Zachodnio-Pomorskie - 153 (34% of all fatalities), Warminsko-Mazurskie - 157 (33%), Pomorskie - 163 (27%), Lubuskie - 89 (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. New measures are required to reduce the hazards posed by dangerous roadside environments.

3. Roadside hazard

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 account of the experience of other countries [13 - 15]. Selected sources of hazards were illustrated with photographic documentation (figure 3 and figure 4). The sources of Poland's most prevalent roadside hazards 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.

All the above examples were identified during a check of Poland's national and regional roads. Sadly, this does not stop there. Accident statistics presented in Section 2 are the consequence of hazardous roadsides, including those along important routes. Below is an illustration of the roadside along one of the most important routes in Warminsko-Mazurskie (north-east of Poland). The region had the highest number of fatalities in run-off-road crashes between 2013 – 2015, (figure 2). The trees along the road are very close to the edge of the carriageway. The hazards here are heightened during winter increasing the risk of run-off-road accidents which in this case will have very serious consequences.

4. Methods to solve the problem

An important part of reducing the "aggressive" effects of roadside on road safety is to ensure that road network safety is managed as set out in the Directive of the European parliament 2008/96/European Commission [16] and that it forms part of road safety management in the broad sense [1]. Road network safety management involves a procedure divided into several steps designed to:

- assess safety and identify high-risk sections,
- carry out road safety checks and identify the hazards and sources of hazards on high-risk sections,
- select the most effective and efficient corrective measures that are appropriate for the funding available,
- communicate the hazards to road users and partners (local authorities, police, and partnered businesses),

- monitor safety levels after treatment and evaluate their effectiveness.

Road safety management can be delivered at three levels: strategic, tactical and operational. This also applies to the problem in question which can be studied for the different levels of risk management.

Strategic risk management occurs primarily when road networks are planned and operated. This is delivered by central authorities and central road authorities. The main sources (factors) of hazard at the strategic level that contribute to the severity of run-off-road accidents include:

- historical legacy – alleys lined up with trees, these can be found in regions previously under Prussian rule, a typical roadside design (this is well reflected on the map in figure 2),
- speeding because drivers notoriously drive over the speed limit,
- existing infrastructure which "forgives" drivers their mistakes on some sections only,
- lack of safe roadside design standards or guidelines for designers,
- conflicts with environmental services (the hermit beetle, an insect, is more important than human life).

If the effects of these factors are to be reduced, we need well programmed actions, effective road safety programmes and plans to support legislation. Roadside hazards are also caused by poor design, construction and maintenance of roadsides. This problem is addressed in a number of programmes and road safety plans. The National Road Safety Programme GAMBIT 2005 [5] dedicates two of its five strategic objectives to the problem of accidents involving striking a tree:

- construction and maintenance of safe road infrastructure,
- reduction of accident severity (by e.g. a "soft" roadside and "forgiving" roads)
- The GAMBIT National Roads programme's objective number 3 aims to "Reduce road deaths as a result of running off the road". This is to be achieved by implementing four strategic actions designed to:
- make roads more recognisable, clearer and more consistent,
- ensure that vehicles stay in lane (signage, narrow hard shoulders),
- shape a safe roadside (safe embankments, safe drainage facilities, removal of hazardous objects (including trees)
- and secure hazardous objects (barriers, crash terminals).

Many of the actions proposed in the programmes (even when facing opposition from a lack of legislative support, activists and environmental bodies and too little funding) have been a significant help with the reduction target. Reinforced by the GAMBIT National Roads programme, the National Road Safety Programme GAMBIT 2005 helped to reduce run-off-road fatalities within 10 years by 30%. It is estimated that by removing roadside hazards (removing trees and securing trees and utility poles) 2 250 people could be saved from death [17]. Despite that in the period of analysis as many as 6 300 people were killed in run-off-road accidents involving striking a tree or other roadside objects. The work started in the previous programming period must be continued under the National Road Safety Programme in the years to come.

Tactical risk management occurs primarily when road networks and parts of roads are planned and operated. This is delivered by regional authorities and regional and county road authorities. The main sources (factors) of hazard at the tactical level that contribute to the severity of run-off-road accidents and require action include:

- the region of the country, 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 county roads;
- road category, roadsides are safer (fewer obstacles, more safety measures) on national roads of higher technical class, regional and county roads are severely affected,
- type of road section (straight section or horizontal curve),
- limited visibility, especially at night-time).

The main actions at the operational level include the design, construction and operation of roads to take account of high risk road sections. They are designed to:

- identify high-risk sections on the road network; risk maps are very helpful with that, prepared in the EuroRAP project (figure 3),
- remove hazardous objects: felling trees, rearranging the objects or relocating the road away from the objects
- secure hazardous objects by using safety barriers and other structures,
- speed management and hazard notification,
- implement roadside safety standards.

Figure 3 Map of individual risk on national roads – run-off-road accidents

A major problem for this level of management is to obtain permits to fell roadside trees posing a hazard to road users. The process can be helped by a recent Supreme Chamber of Audit report on road safety management which addresses this particular problem (NIK, 2014). Operational risk management occurs primarily when road structures are built, operated and deconstructed. This is delivered by local road authorities and local authorities.

The main sources (factors) of hazard at the operational level that contribute to the severity of run-off-road accidents and require action include:

- narrowing of road and roadside which forces vehicles to drive on the opposing traffic lane (head-on collisions),
- reduced visibility at junctions and exits (side impact),
- road signs covered up (road not clear and understood),
- no space for pedestrian traffic and reduced visibility at pedestrian crossings (hitting a pedestrian)
- causing damage to road infrastructure,

The main actions at the operational level include construction and operation of roads to take account of:

- better visibility through special signage or removing trees at junctions to ensure visibility,
- using the 2-1 cross-section on county and regional roads (tests have been conducted in Chojnice area – Fig. 7a),
- use of local speed limits (70 or 50 km/h),
- special signage – least effective (Fig. 7b).

The success of operational level management depends on the quality of efforts at the higher levels. The funding at this level of management is insufficient to fund prevention and treatment. As a result, local roads are usually treated by putting up signs, reducing speed and felling trees. Poland's efforts to reduce roadside hazards frequently build on European initiatives [18].

5. Modelling the effects of roadside on road safety

Analyses of models of how roadside elements affect road safety [19 - 22] showed that the methodologies and data differ from model to model. Because the models focus on different factors, they each have strengths and weaknesses.

The new analytical model was designed as a combination of the different factors and one that will serve as a comprehensive model for Polish conditions. It was assumed that it will describe the effect of the roadside on the number of accidents and their consequences. The design of the model was based on recommendations from analysing other models. The assumptions were the following: the model will be used to calculate risk factors and accident severity, the indicators will depend on number of vehicle kilometres travelled or traffic volumes, analyses will be based on accident data: striking a tree, hitting a barrier, hitting a utility pole or sign. Additional data will include roadside information and casualty density measures will be used – killed and injured.

The study was conducted for national roads in the region of Pomorskie. The first phase of the study was designed to build an inventory of roads and build accident databases. The next stage was to develop mathematical models to show the correlations between roadside and accidents. All analyses were based on the SEWIK database. The accident database included information about accidents and collisions involving running off the road. A period of three years (2013-2015) was selected and served as the basis for all calculations and models. The inventory covered sections of national roads at the total length of about 777 km (except national roads in urban areas). There were separate inventories for the left and right edge of the roadway and the central reservation (in the case of dual carriageways). Potential roadside hazards were identified (trees, embankments, utility poles, engineering structures) and selected type of barriers (concrete, steel, ropes).

To ensure that data were collected consistently, two databases were built: roadside database and accident database. The primary data that were imported into the databases at the start included Road Data Bank information about reference sections with details on: section length, traffic volume, number

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of vehicle kilometres travelled and share of hard shoulders. With the large set of data already in place, reference sections were used for collecting roadside information and creating computational models. The roadside database had about eight thousand records – measurement sections assigned to reference sections 1 – 5 km long. The records contained data about section length, annual average daily traffic flow, number of junctions, exits, signs, utility poles and percentage share of sections with barriers, trees, embankments and hard shoulders depending on their width.

The chapter presents the analyses and results of the GOF victim density rate. The objective of the model is to estimate the expected number of victims of accidents on national roads per kilometre of road over a specific period. The victim density model is described with the following formula:

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

where:

GOF(Y) 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
B, S, T_1, T_2, T_3 C, P_1, P_2, P_3 factors related to the risk of an accident (independent variables)

The model has a determination coefficient (R^2) equal to 0.85.

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

	Coefficients		Value	Lower confidence limit	Upper confidence limit	p-Value
	Adjustment	α	1.14E-07	1.14E-07	1.14E-07	0.00
Traffic volume	Q	β_1	0.67	0.31612	1.03195	0.00
% of barriers	B	β_2	-3.02	-4.48932	-1.55423	0.00
% of embankments	S	β_3	1.73	0.48282	2.99325	0.00
% of trees to 3.5m	T_1	β_4	2.85	1.98812	3.71178	0.00
% of trees above 3.5m	T_2	β_5	1.25	0.62473	1.87844	0.00
% of forests	T_3	β_6	-0.46	-1.46917	0.54344	0.00
Road class	C	β_7	8.66	2.70382	14.62712	0.00
% of shoulders above 1.5 m	P_1	β_8	-0.63	-0.92808	-0.32719	0.00
% of shoulders to 1.5 m	P_2	β_9	-0.46	-1.05439	0.13582	0.00
% of soft shoulders	P_3	β_{10}	0.17	-0.75521	1.09778	0.00

6. Results of the study

The effectiveness of road safety measures largely depends on how intensively evaluation tools are used to understand the benefits. These tools include prognostic models. They can be used to identify high risk sections or study the relation between road section features and the potential for accidents. An analysis of the study in Pomorskie shows that victim density declines as the percentage of section with barriers and hard shoulders increases. The results of the study are presented for single carriageways in outside built-up areas of class GP (trunk road with higher speed limits). The number of victims depends on trees within a distance of up to 3.5 m, embankments and trees further away (more than 3.5 m from road edge).

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. 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.

7. Conclusion

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.
- with no regulations, design standards and cooperation with environmental organisations and institutions, human life is valued below that of trees, lichens and insects.
- 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.

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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