

SELECTED ASPECTS OF ROAD SAFETY IN POLISH ROAD DESIGN PRACTICE

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ABSTRACT

The road safety situation is very similar in Central and Eastern European Countries (CEEC's). All these countries have faced an important or even dramatic deterioration in road safety level in recent years. The transition to a free market economy has caused certain road safety problems in terms of road users, roads as well as vehicles. The classification of accident causes differs from country to country. As for Poland, almost all traffic safety indicators are located on one of the last positions in Europe with mortality of traffic accidents victims at the level of 14%, while the average in European Union is about 3.4%. It is not possible to state precisely what the reasons for the trend are in terms of higher fatality figures, but undoubtedly, there are two types of reasons:

1. social explanations,
2. traffic system explanations related to the increasing traffic volume, maintenance of road and vehicles, traffic regulations.

An important group of effective measures related to the second mentioned reason is found in the field of infrastructure and the road design process. Some considerations on road design standards used in Poland, especially in safety aspects, are undertaken. Research results obtained at the Gdansk Technical University show that there is a need to modify design practice in terms of modernization of cross section of many two-lane roads, markings of horizontal curves and a correct selection of geometrical elements of the horizontal alignment.

INTRODUCTION

Polish road design regulations (1) comply with the terms resulting from the document titled "Annex II of the European Agreement on Main International Traffic Arteries" (AGR) (2) prepared by the Transportation Committee of the European Economic Commission. This document is the basis for unification of road design standards for roads encompassed in the European road network. Polish regulations of road traffic signing also comply with the terms of the Vienna Convention on Road Traffic Signs and Markings (3).

The necessity to unify road design regulations in Europe was also stressed in the Treaty of the European Union (Maastricht). "The European Road Network (TEN)" (4) term was defined there.

The situation in European countries in terms of

adjusting the road networks to the terms set forth by the AGR Agreement and the Vienna Convention is not explicit. Some countries have ratified the conventions, others have not; nonetheless it is the latter that adopted the main recommendations resulting from the conventions.

The first European global road solution which respects the principles of road design standards unification is the TEM (Transeuropean North-South Motorway), currently under early construction, from Gdansk (Poland) to Istanbul (Turkey) with connections to Austria, Greece and Italy (5). The layouts for TEM were prepared under the supervision of the United Nations Development Programme in the mid seventies. The central design office was located in Warsaw. At the same time in Poland, a project for road network modernization of two-lane and two-way roads was under way in order to adjust the network to the requirements posed to Main International European Arteries.

The road safety situation is very similar in Central and Eastern European Countries (CEECs). All these countries have faced an important or even dramatic deterioration in road safety level in recent years. A number of reports written recently give an image of road safety in CEECs (6).

SCIENTIFIC KNOWLEDGE ON THE EFFECTS OF ROAD MODERNIZATION ON ROAD SAFETY

From the stand-point of road safety, road modernization is not an easy task. This is mainly due to the level of current scientific knowledge, which does not allow for an exact explanation of the process leading to a road accident. It is even more difficult to specify the effects of road modernization on changes in this process and how it happens. In this context, scientific evaluation of road safety aspects in the process of road design seems to be a complicated task, because:

1. we don't have a clear view on the criteria for evaluating the elements of the road accident process and we also lack demographic data on its participants. Basically, apart from the sex and age of the casualties, we know little about their professions, employment, educational background, income, family, reason for journey, transportation means, consumption structure (including alcohol), ways of spending leisure time, etc. And it is these data that can tell us what the relation between a road feature and the behavior of road user is in the

critical moment,

2. we have doubts as to the usefulness of typical measures to evaluate risks in road traffic in general, and especially the risks generated by construction elements or road environment. Currently we know and apply various road accidents indicators, and each of them represents a certain point of view (global, local, individual, collective, drivers' and pedestrians' views, etc.) whereas often they should be seen as parallel.

The doubts we are having as to the adequacy and usefulness of road safety evaluation indicators are a sufficient justification of the question: "What road safety aspects in road design are we supposed to discuss?" In spite of the by now commonly recognized importance of safety as a criterion in the process of planning, designing and road operating, neither science nor engineering practice have so far provided sufficiently clear answers to the questions on the relations between road geometrics and road safety. The papers published on the effect that one geometrical road element has on road safety usually report a change (most often a decrease) in the number of road events in given conditions after the element had been modernized. In the conclusion of our research we usually generalize this statement; however, we are aware that it is only the researched element (not a family that it belongs to) in certain road, traffic and atmospheric conditions (terrain configuration, road geometrics, its environment, traffic volume, traffic structure) that has such an effect on road safety.

However, such generalizations create a certain additional risk in the form of apparent effects. Modernization of a certain road element usually causes an increase in vehicle speed, which is usually higher than the new traffic conditions allow for. As a result drivers enter the old road elements directly adjacent to the new one at a speed above their abilities, which often times ends in an accident. In practice it is usually difficult to combine the two facts together, if you don't know much about accidents migration and you don't collect exact data on road events on a regular basis. Besides, we know that modernization of one element in a road network often causes a change of mobility patterns within the network and as a result a change of volume at its particular elements.

Despite the doubts, we are convinced that design standards, directives, and design procedures which shape the road system are targeted at road safety, in a wide meaning of the word, and nobody has any doubts as to the sincerity of their authors' intentions. Nonetheless, basic knowledge of the relationships between engineering decisions and their consequences for road safety is still very modest. As a result road safety is not

seen as a top priority among the whole range of road design criteria. Therefore the only conclusion is that improvement of the current status is possible only through improvement of the relationship between research and directives.

The majority of road infrastructure is historically conditioned and as a result it does not meet the requirements of the modern vehicle, driven by a man living at a modern pace. Engineers modernize the critical points or sections of the infrastructure, and designs of new roads usually incorporate the operating experiences of previous roads. Despite the fact that engineering activity in that field has a crucial and positive influence on road safety issues, road safety is alarmingly low, and social losses related to accidents are very high. Still it is very difficult to convince the government that despite the high "effect/investment" indicator, it proves to be extremely successful in improving road safety through road modernization.

PHILOSOPHY OF ROAD DESIGN

From the stand-point of road safety, a proper design has a crucial significance in preventing road users' errors. When the numbers and significance of these errors are decreased, the number of deaths and injuries and material losses also decreases. The obvious truth can be supported by three main principles, which say that a well planned road should:

1. prevent unintended ways of its usage (type of road vs. traffic structure, type of road environment vs. vehicle speed; that is, road function vs. type of traffic),
2. prevent conflicts by unification of vehicle flows from the stand-point of their speed, driving direction, or mass of vehicles,
3. prevent insecurity in the road user's behavior, at the same time making it possible to foresee the user's reaction.

Fulfillment of the three principles in the design process should be a great help in adapting the road to modern traffic and securing a higher level of its safety. Therefore the starting point for the analysis of road design directives in terms of road safety should be the key issue of "design speed", which is the main road design parameter. This approach to design has not changed for a few decades even though based on scientific research carried out in that period it was proved clearly and logically that speed has a great and "effective" influence on the occurrence and severity of road accidents. The speed level secured by the road and its environment seen as safe by the driver results in an increase in desired speed. Administrative measures applied to limit it do not

bring about desired effects.

Generally two definitions of speed are mentioned as a criterion for road design:

1. the highest constant speed on a road section in certain atmospheric conditions, a speed which secures a safe drive unlimited by the presence of other vehicles, known as "design speed" according to that latest AASHTO concept (7) or as "basic speed" according to AIPCR concept (8),
2. the highest speed at a critical element of a road section, known as reference speed (*vitesse de reference*) according to the French DRCR conception (9).

This philosophy of approach to road design still arouses discussions and leads to two principal contradictions in the concept of modern transportation systems functioning:

1. The concept of "design speed" which implies that "the better the road the higher the design speed is" contradicts another concept which results from the current approach to the important social problem of road accidents. Very well-known in Poland, an American approach to the criteria of traffic conditions classification, called the HCM method, uses the term "level of service". In this approach to the issue, higher comfort is inseparably linked with a higher operating speed capacitated by geometric road parameters. However, the increasing traffic volumes cause an ongoing discrepancy between speed patterns. This is creating a new phenomenon, called "speed inflation" as a criterion for road design.
2. Observation of drivers' behavior on various road sections shows significant differentiation between the actual speed of vehicle flow. Beyond critical road sections, the observed speed exceeds road design speed by about 20 km/h. The average speed of a vehicle flow on sections with local speed limits approximates the value of the limit, which means that about half the drivers do not respect the limit. French research on vehicle speed in the function of geometric elements of rural roads (10), and also a lot of Polish research (11, 12), showed that three elements had the biggest effect on speed:

1. horizontal curvature,
2. road cross section type
3. grade.

ROAD CROSS-SECTION

Elements Affecting Width Standards

The factors that determine the cross-section are:

1. road network factors: road function, design speed,

average trip length of vehicles;

2. traffic factors: traffic volume, types of vehicles using the road, width of passenger cars and heavy vehicles, number of pedestrians, volume of cyclists;
3. road factors: alignment, drainage, number and function of traffic lanes and shoulders, construction practice, maintenance procedures;
4. human factors: drivers' behavior in speed and lateral position, behavioral adaptations, feeling of security;
5. environmental factors: landscaping, access requirements, aesthetics;
6. safety considerations: accident rates, severity of accidents, accident costs;
7. operational requirements: required level of service, capacity, delays;
8. benefit/cost analysis: construction, maintenance, accident and operational costs.

Operational effects of lane and shoulder width can be analyzed through the use of lanes by different types of vehicles, the use of shoulder by moving and stationary vehicles, lateral position, running speed of vehicles, freedom of maneuver and operating costs.

The conclusions of studies looking to the relationships between lane width, shoulder width and shoulder type and accidents, especially on two-lane rural roads, were often not only inconsistent, but in many cases contradictory. Nevertheless, findings show that rates were the highest for run-off-road and opposite-direction accidents for narrow lanes and decreased as lane width increased. Rates for other accidents generally increased as lane widths increased. It means the only accidents that would be expected to decrease with lane widening were run-off-road and opposite-direction accidents. As with lane width, the run-off-road and opposite-direction accident rates decreased as shoulder width increased to 2.7 m. There was a slight increase in accident rates for shoulders 3.0-3.7 m wide. Analysis of the combination of lane and shoulder widths indicates that a greater reduction in accidents can be realized by lane widening rather than by shoulder widening. However, the unadjusted accident rates were approximately the same (or slightly higher) for 3.6 m lanes as for 3.3 m lanes, possibly indicating the limit beyond which further increases in lane width are ineffectual.

The analysis of the total economic consequences of the choice of road cross-section type and its optimal dimensions requires the inputs of some costs components into the calculation. From a practical point of view, parameters can be divided into three groups:

1. parameters independent of the road: length of time period in question, opening year, traffic

- development, percentage of heavy vehicles;
- 2. parameters dependent of the road: capacity, volume/speed relationships, accident rates, construction costs, maintenance costs;
- 3. economic parameters: costs per accident by severity, hourly price for cars and heavy vehicles, driving costs, discount rate.

Comparison of EU Design Standards

A few standards give explanations on the established width of cross-section elements. Sometimes standards present different approaches to the chosen road alignment and cross-section dimensions, definitions and importance of design speed, possibilities of departures from standards as well as the role of guide-lines for users in the designing process (13).

Minimal width of traffic lanes and paved shoulders depends first of all on design width of vehicles and side margins determined by lateral position and dynamic space of moving vehicles. For rural roads the width of the "design heavy vehicle" is established. Usually in Europe it is 2.5 m, in the Netherlands 2.6m is allowed. In German standards, minimal lane width results from the sum of 2.5m heavy vehicle width, 0-1.25 m side margin and 0.25 m additional space strip, if there is an opposite traffic lane. It creates a traffic lane width from 2.75m to 3.75m. Side margins depend on speed limits.

The comparison of motorway cross-section width shows relatively great agreement of standards. The majority of EU countries use a lane width of 3.75m. The width of 3.25m is rarely used and only for a design speed of 90km/h. For paved shoulders, only two countries use a width below 2.5m.

Non-motorway divided roads showing one or more motorway characteristics have high accident rates. The use of wide paved shoulders on these roads in different countries depends on some additional factors like road network structure, landscaping and multifunction of the road link. Even though wide paved shoulders can have some advantages for safety, the possibility of emergency stopping is probably only a minor benefit. Therefore, a paved shoulder with a width comparable to the full width of an emergency stopping lane does not seem to be necessary.

Undivided rural roads have considerable different dimensions of traffic lanes and shoulders. In many cases two-lane roads with wide paved shoulders are used like four-lane roads.

The standards and guidelines which are used in EU Member States present different approaches to the design process offering a range of facts, assumptions, explanations, rules and recommendations.

It is stressed in some standards that the designer will have to choose the road types according to the criteria dictated by economical analyses. Sometimes conditions like the inadequacy of the area or the size of earthworks provoke the reduction of cross-section width. French guidelines propose a certain succession of reductions. Danish standards propose the narrow type of cross-section for dual carriageway roads. Also British standards use special cross-sections with restricted width.

Polish Standards

Now the Polish road network has 1,100 km of two-carriageway links with only 130 km of motorways. Because of it, main safety problems come from two-lane roads. The structure of two-lane roads in Northern Poland is depicted in Figure 1.

Lack of financing for the construction of a freeway network in Poland dictated the necessity to prepare a project for modernization of main two-lane roads in Poland. The characteristic feature of these roads was that they were multifunctional and easily accessible. The main objective of the modernization was to segregate fast traffic (passenger cars, delivery trucks) from slow traffic (pedestrians, cyclists, horse carts, tractors, slow trucks) and also to partly limit access to these roads and at the same time maintain the route of the road. As a result of modernization works performed in this aspect, the outcome was a road with two lanes (2x3.00m) with paved shoulders 1.50-2.50m wide.

After the modernization in the early stages of the operating period of the roads, the speed of fast vehicles increased significantly due to the use of paved shoulders by slow vehicles, and pedestrian and cyclist traffic safety increased because shoulders were a designated zone for this type of traffic.

However, 20 years later the by-type structure of road traffic changed decisively. Fast passenger cars have a much bigger share in the flow, and horse traffic has almost completely disappeared and motorcycle traffic diminished. In this situation two-lane two-way roads with paved shoulders are treated by the users as four-lane roads. As a result of this change in traffic structure, pedestrians and cyclists became more exposed to the risk than before the modernization. Figure 2 shows results of research on the effect of pavement width on road safety in the function of road traffic volume (14).

In Polish urban conditions, a four-lane two-way cross-section (1x4) became the most dangerous cross-section of a street (15). High accident rates on these streets were observed in a situation of increased traffic volume and increased access to these streets (Figure 3).

From safety research one can conclude that:

1. on higher speed two-lane roads, a paved shoulder can have a width of 1.8-2.0 m, and a different color of the shoulders could stress the special functions of these lanes,
2. use of emergency lay-bys every kilometer and wide verges can be recommended to design practice,
3. in many cases, using three-lane roads (2+1) is more profitable in safety terms.

All the above-mentioned measures are unknown in Polish design practice.

HORIZONTAL ALIGNMENT

Running Speed on Curves

Regarding the curves, the most part of national road "standards", and also the AGR agreement, have a sort of common basis which contains the design speed concept. Some countries have introduced complementary rules or approaches, taking into account the actual speeds, and/or defining the conditions of the succession of the different elements of horizontal alignment. The main difficulty is that the conventional design speed approach is not sufficient to cope with some important safety problems at curves (16).

Some countries have introduced the actual speed in their standards. The difference between this speed and the design speed is examined, and, if this difference is too large, the design speed or the alignment is modified. The standards of another country introduce the calculation of this actual speed at each point of the alignment, but only for the control of sight-distance conditions.

Statistical studies have shown that actual speed strongly depends on the local characteristics at a given point (mainly: curvature, cross-section, gradient).

Polish research (11) proves that both the curve radius and the curve angle affect the vehicle speed greatly (Figure 4). Both of these parameters have a big effect on the value of the friction factor used by a vehicle, connected with the traffic safety margin of the vehicle. Similar to other European research, a relation between free-flow speed and road curvature was achieved which is the relation between the sum of angles of horizontal curves to road length (Figure 5) (12).

Research results suggest that safety problems due to horizontal alignment inconsistencies cannot be completely reduced to a speed question. Even in the same speed conditions before a curve, a severe bend will be more or less expected by the driver, depending on the curves he has encountered on the road before. This will influence the reaction time of the driver and the

correctness of the assessment of the bend characteristics.

Safety on Curves

Statistical studies show that the accident rate (accidents per vehicle kilometer) is high for the low values of radius, and decreases when the radius increases. This interdependency was achieved for Gdansk Region roads (Figure 6).

The alignment in which a curve takes place is very important in the determination of the safety at this curve. The accident rate at small radius bends is very high when the average curvature of the whole alignment is low, but relatively low when the average curvature is important. High accident rates are observed at a bend when it follows a long straight line, when its radius is smaller than the radii of preceding bends and when the number of bends per kilometre is low.

Other external factors have been found as relevant for road safety: severe bend in a steep down grade, short-sight distance (during the approach) on the bend or on the end of the curve.

Some studies show that internal factors (depending on the design of the curve itself) also have important effects on safety, especially at bends having a small or medium average radius of curvature.

Concerning the signing of a curve and its effects on safety, it seems that research results are still insufficient to constitute a solid background for improving the standards.

New Polish regulations already include the principles of selection of neighbouring horizontal curves and the determination of curvature depending on the actual running speed. As yet, these principles have not been verified in practice in terms of road safety.

CONCLUSION

Road safety aspects in directives for road design are an important and complex issue. It can only be solved in a systematic and interdisciplinary way with close cooperation with experienced foreign institutions which are currently working on the unification of road design regulations in Europe. The question, however, arises whether we already have a clear picture of strategies for a long-term development of the transportation system in European countries, a system which would take into account the requirements of European Union targeted at decreasing risks in transportation. What should be done in the first stage is to analyze the data and assumptions which were the basis for preparing directives, and then classify them according to their credibility.

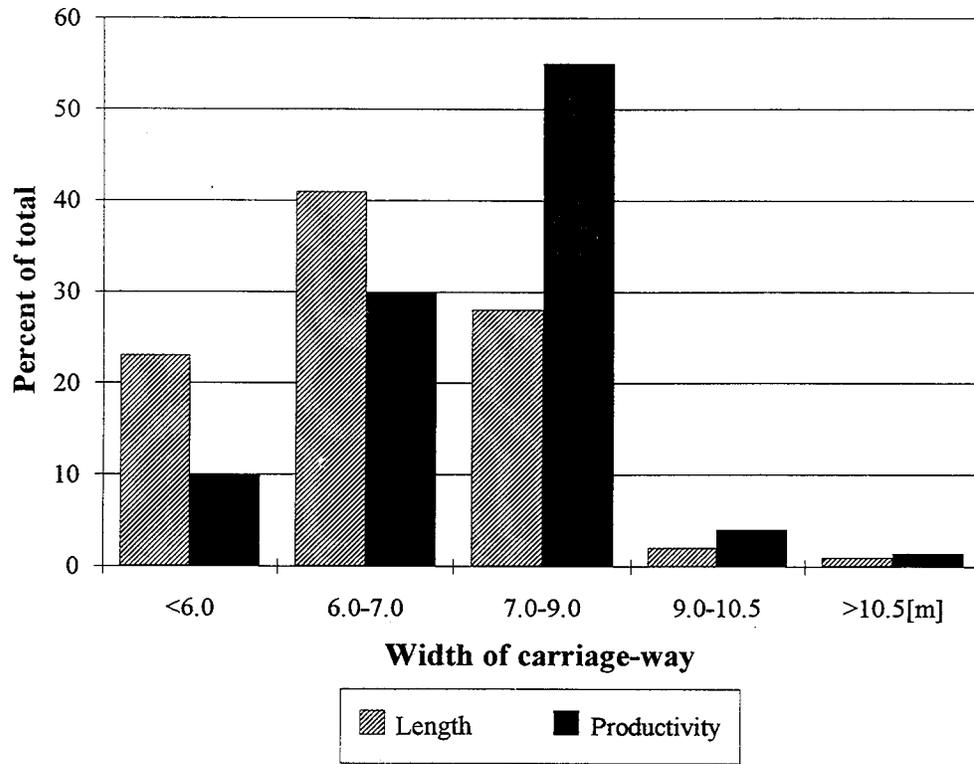
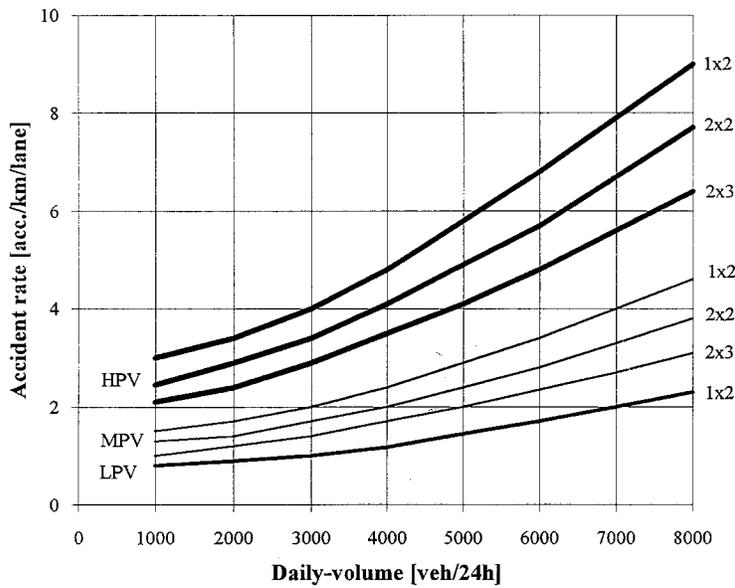


FIGURE 1 Percentage Length and Productivity Versus Type of Cross-Section in Gdansk Region



LEGEND:
 HPV - high pedestrian volume
 MPV - moderate pedestrian volume
 LPV - low pedestrian volume

FIGURE 2 Accident Rates Versus Daily Traffic Volume and Road Width

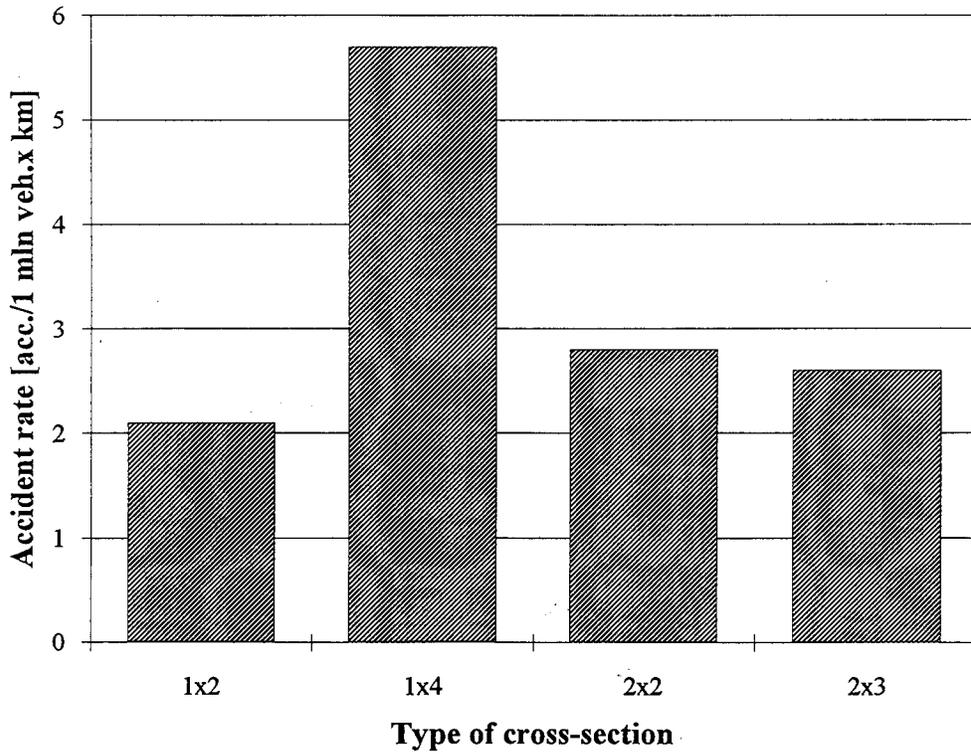


FIGURE 3 Accident Rates Versus Type of Street Cross-Section

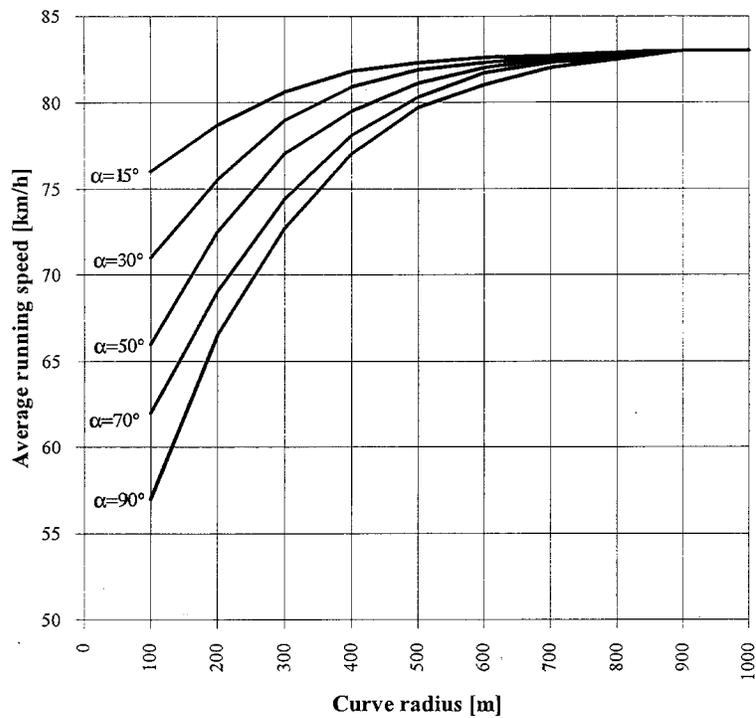


FIGURE 4 Average Running Speed Versus Curve Radius and Angle of Deviation

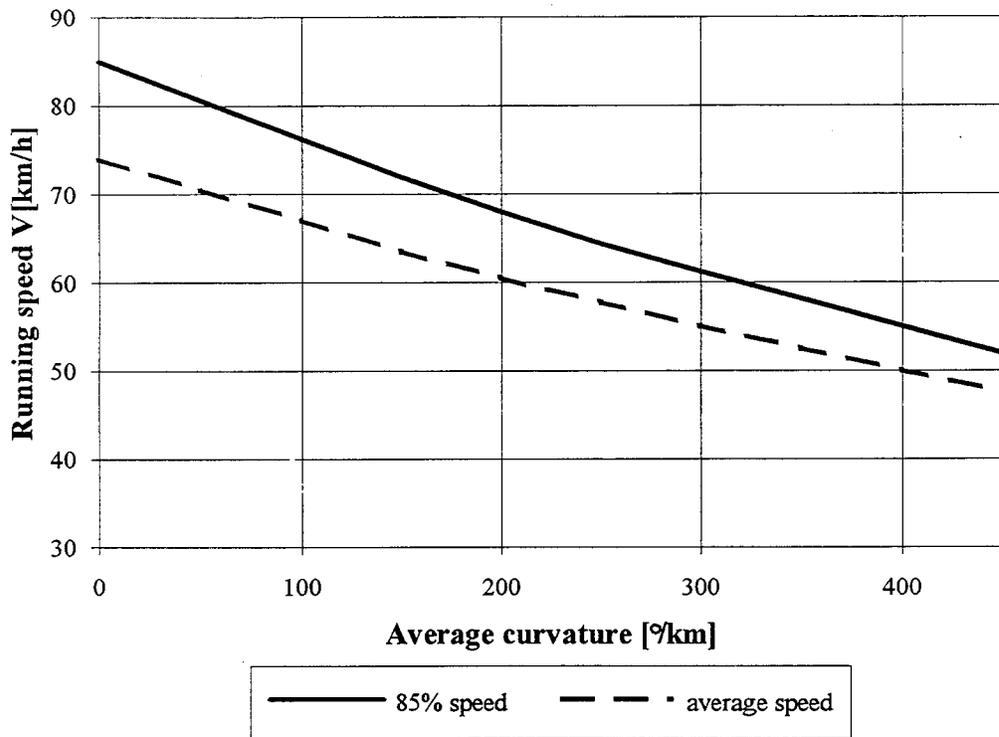


FIGURE 5 Average Running Speed Versus Average Curvature of Road Section

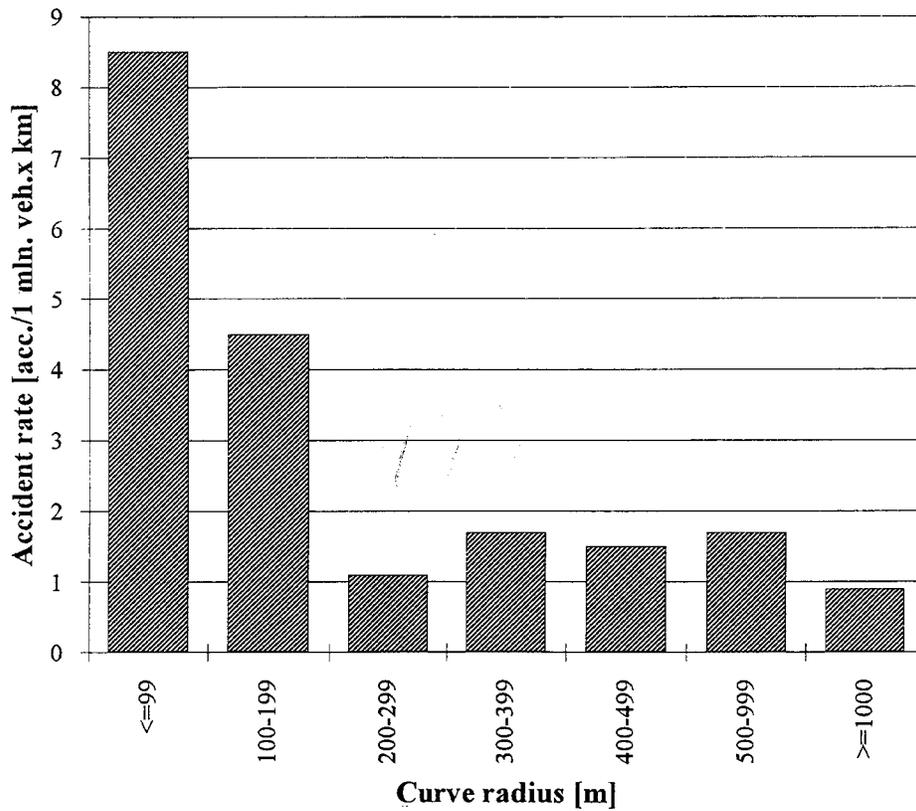


FIGURE 6 Accident Rates Versus Curve Radius

In this way we will come up with material comparable with the European Union's directives. Next, the following should be designed:

1. directives on how to transform the existing roads into roads which would meet the requirements of functional classification,
2. instructions on how to collect and process data on road events to designed modernize roads and intersections,
3. a catalogue of solutions of intersection modernization in terms of road safety.

Road safety should rank higher on the list of criteria for road design. In order to achieve that we need to verify methods of evaluating social losses related to road accidents. The current costs assumed for a road accident rank road safety at the lowest position on the criteria list, and any applications for additional financing to improve road safety are destined to fail.

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