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Relationship between road width and safety

1 INTRODUCTION

Road accidents have made a serious contribution to death rate in the Czech Republic for a long time. In the course of time accident frequency trends changed several times, however current numbers are still unsatisfactory. Since 2002 there have been activities following the *White paper* (European Commission, 2001) with goal of halving the number of persons killed in road accidents by 2010 compared with 2002. A significant road safety improvement was achieved, however the goal was not reached. This situation calls for further strengthening of effort.

Safety, as a multidisciplinary component of the transportation system, is built on three pillars: the vehicle, the road user and the road environment (ie. geometry and other characteristics). According to PIARC (2003), an accident is considered a disruption of the balance among three mentioned pillars. The number of accidents is used to derive the measure of level of safety; typical variable, used in in the Czech Republic most often, is accident rate. However, number of studies (eg. Hauer, 1997) recommends using accident frequency instead. It is defined as a number of accidents in specific period of time.

2 ROAD WIDTH

Recalling mentioned pillars, this paper focuses on road geometry, and more precisely on road width. According to Gatti *et al.* (2007), it is the most appropriate value to characterize the cross section.

What is the effect of road width on accident frequency? According to Elvik *et al.* (2009), increasing the road width reduces the accident frequency on rural roads, but may lead to a small increase in accident frequency in urban areas. The reason is that road width in towns and cities makes crossings wider, so that pedestrians need more time to cross the road. In rural areas, increased road width may provide a safety margin, because speed is higher than in towns.

However, the road width consists of lane width and shoulder width, in some cases even the width of median barrier. All these parts make up the overall road width. Regarding relationship between shoulder width and safety, Elvik *et al.* (2009) conclude that wider shoulders almost always result in fewer accidents. Hauer (2000) states that shoulder width is more beneficial to safety at higher traffic volumes than at lower ones. Strathman *et al.* (2001) found more accidents on motorways with wider shoulders than on motorways with narrow shoulders. Gatti *et al.* (2007) lists both positive and negative aspects as well.

In addition, all the results are not definite: Elvik *et al.* (2009) state that there is no relationship between road width and accidents when controlling for traffic volumes and speed (Garber and Erhard, 2000).

However, most of these results come from studies performed in Western Europe, Nordic countries and Northern America. These are all countries with certain level of road safety culture. It is questionable to think that the same will automatically hold in the Czech Republic as well. The paper searches for the answer to this question.

3 DATA

Data needed for road environment studies come from three data sets: accident data, road network data and traffic volume data.

Accident data

Accident data are reported by Czech Traffic Police. They include information on the accident, its location and all the vehicles and users involved. In total 59 items are registered for each accident.

According to their consequences, accidents are sorted as property damage only (PDO) and injury accidents (including accidents with light injuries, serious injuries and fatalities). However with PDO accidents, there is a financial limit for reporting to the Police: while up to 2009 it was 50 000 CZK (approx. 2000 €), since 2009 it is 100 000 CZK (approx. 4000 €). Only accidents exceeding this limit are reported to the Police. Thus accident data suffer from underreporting.

Since 2007 all registered accidents are located with use of GPS which improves the location precision and further processing. In the Czech Republic three-year period is considered sufficient to base accident studies on – thus three complete years (2007, 2008 and 2009) of records were used. 2010 data were not yet available at the moment of writing.

Road network data

Road and traffic data were obtained from Road and Motorway Directorate of the Czech Republic (ŘSD). Road network data cover most of the Czech road network. They are

collected continuously and updated twice a year. In the paper data set from the first half-year 2007 was used in order to match with GPS located accident data starting since 2007.
The part which is the most relevant to the topic is the *road passport*. It consists of interrelated databases of sections and intersections. Only sections were considered in the paper. Their database includes data related to each road section – road and lane width, presence of trees, description of median barrier, road surface, passive safety systems and many others.
Section is defined as a segment of the road with uniform parameters. Whenever any parameter changes, the section ends and another one begins. Due to this fact, lengths of sections are not equal. In order to be able to use length in further calculation, section length values should have the same statistical distribution for both compared groups. The histograms of section lengths for both road width ranges are given in Fig. 1.

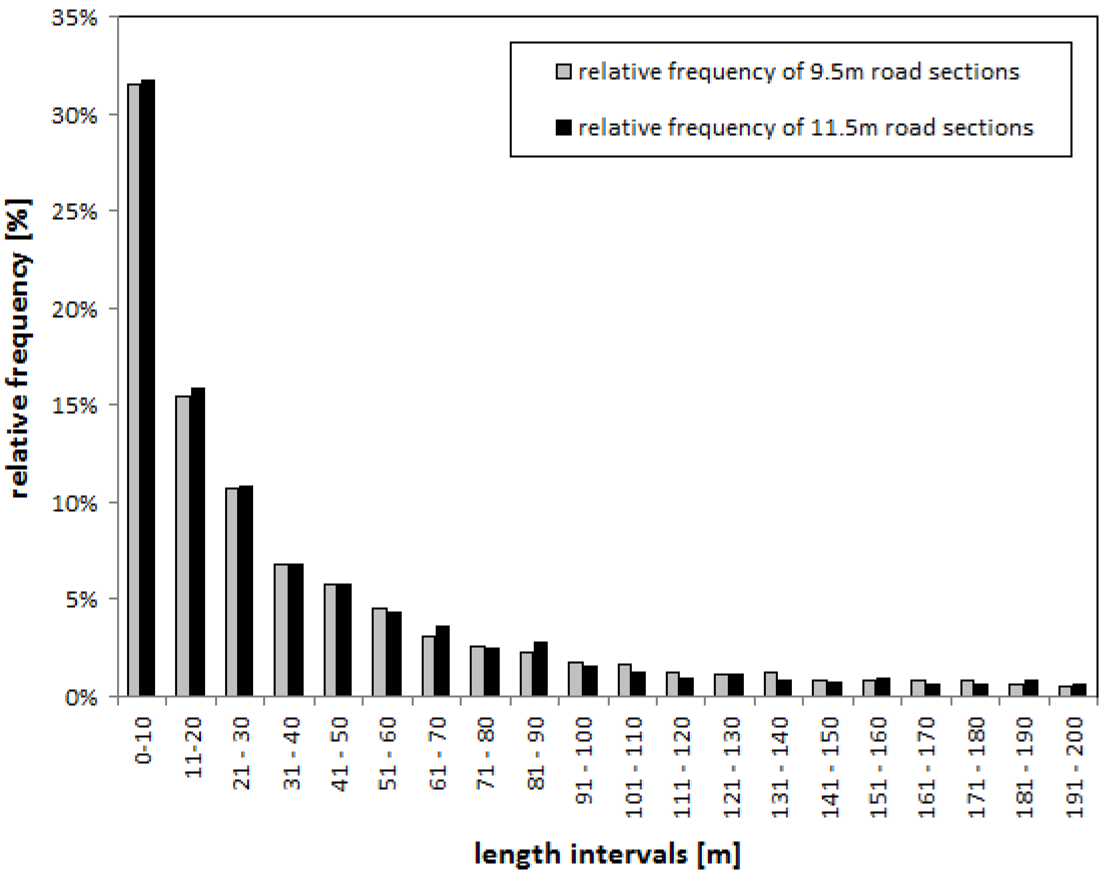

Fig. 1 Histograms of section lengths for both road width ranges

The two histograms of section lengths show similar shapes. To compare the distributions of both populations, a two-sample Kolmogorov-Smirnov test was performed. The test statistic is $D = 0.013$. The null hypothesis of different distributions was therefore rejected.

Traffic volume data

Traffic volume data come from National Traffic Census which is organized every five years. The last census was performed in 2010, however its results have not been published yet. Therefore data from 2005 were used.

Census data cover all the motorways, expressways, 1st and 2nd class roads. Some of 3rd class roads are not included. The results of traffic census include annual average daily traffic volume (AADT) on every section in 13 vehicle categories.

Data selection

As mentioned above, data sets provided by ŘSD were very large. In order to form relatively homogeneous group, selection of road width category had to be made. Therefore 9.5m and 11.5m roads were selected. According to České dálnice (2010), these categories of roads are the most frequent in the Czech road network (excluding expressways and motorways). Only two-lane road sections (with one lane in each direction) were selected.

These categories fit to the Czech national standard for design of highways and motorways (ÚNMZ, 2009). Design categories parameters are listed in Tab. 1.

Tab. 1 Design parameters of selected road categories according to ÚNMZ (2009)

design category	width			
b [m]	*a* [m]	*v* [m]	*c* [m]	*e* [m]
9.5	3.50	0.25	0.50	0.50
11.5	3.50	0.25	1.50	0.50

The following symbols are used:

b … road width

a … lane width

v … width of carriageway marking

c … width of paved shoulder

e … width of unpaved shoulder

Values in Tab. 1 show that the only difference between 9.5m and 11.5m roads is the shoulder width. The meaning of symbols is illustrated in Fig. 2.

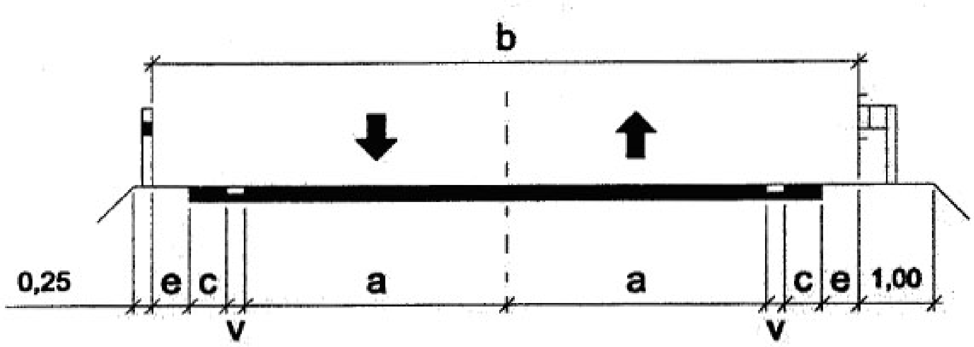

Fig. 2 Cross section of two-lane road (ÚNMZ, 2009)

4 METHODS

The aim is to analyze road width and its impact on safety. The data selection includes two-lane roads of 9.5m and 11.5m width (single carriageway with no median barrier). Selection was not random – it covered the whole Czech Republic. Following steps – including stepwise reduction of selected data set – were performed:

4.1 Rejection of PDO accidents

Due to mentioned legislative change of reporting limit, number of registered PDO accidents fell down significantly in 2009, biasing the statistics. On the contrary, the numbers of injury accidents (light injuries, serious injuries and fatalities) are not biased by this change – see Fig. 3.

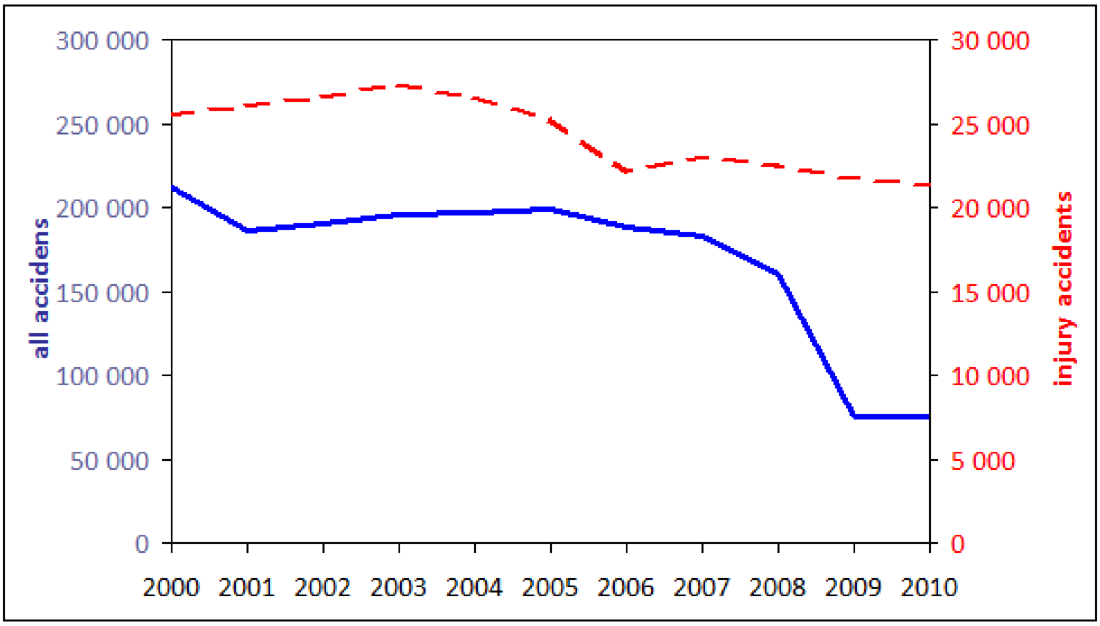

Fig. 3 Time series of number of all accidents and injury accidents in 2000 – 2010

In the paper, period between 2007 and 2009 is studied. To overcome the mentioned bias, only injury accidents were used in the calculation.

4.2 Rejection of non related causes

General accident causation comes from Police accident investigation. While it is questionable and may be subject of thorough analysis, the Police only assigns one single cause to each accident, chosen in a pre-defined list.

However not all the causes are related to the purpose of this study – for example accidents due to failure to yield the right-of-way or vehicle technical failure. Following the above mentioned statement by Elvik *et al.*, 2009 (*the increase of width should provide more space for overtaking and speeding, resulting in lower accident frequency*), the accidents considered were restricted to overtaking and speeding causes, which induce the most serious accidents. The same restriction was applied also by Kafoňková and Andres (2008). The final list included thirteen causes (see Tab. 2).

Tab. 2 Selected causes of accidents for this study

Speeding	maladjustment of speed to traffic operation density
	speed higher than speed according to traffic rules
	speed higher than speed indicated by traffic sign
Incorrect overtaking	overtaking to the right
	overtaking without sufficient side distance
	overtaking without sufficient sight (at the curve or its proximity, in front of summit etc.)
	during overtaking a driver in opposite direction was endangered (wrong estimate of distance etc.)
	during overtaking an overtaken driver was endangered (enforced entering, violent braking, change of ride direction etc.)
	overtaking in places where the overtaking is forbidden by traffic sign
	overstepping the separation line during overtaking
	overlooking the vehicle already overtaking
	other kind of incorrect overtaking
Incorrect driving	driving on the wrong side, entering the opposite direction

4.3 Grouping according to traffic conditions

To make valid safety comparisons, Hauer (2005) recommends to compare the expected accident frequencies under the same conditions. Such conditions include traffic speed and traffic volume.

Speed limits in the Czech Republic are set to 50 kph in urban areas and 90 kph in rural areas. It is therefore important to distinguish between sections in urban and rural areas. Such grouping is commonly applied in safety performance functions – see eg. Reurings *et al.* (2005). This report also states that traffic volume is the most significant factor for accident frequency. Traffic volume conditions were defined so that they reflect the Czech national standard (ÚNMZ, 2009) design volume limits. The limits are 10 000 vpd on 9.5m roads and 12 000 vpd on 11.5m roads. Therefore traffic volume conditions were set as follows:

- according to the design limit (up to 10 000 vpd on 9.5m roads, up to 12 000 vpd on 11.5m roads)
- exceeding the design limit (over 10 000 vpd on 9.5m roads, over 12 000 vpd on 11.5m roads)

These two volume states were named as *standard* and *high*; their sum is *total*.
In order to take volume into consideration, only sections with known AADT were used for the study. As it was mentioned in chapter 3, the census results cover most of the Czech road network. Because they reflect the 2005 census, AADT values were corrected to values of 2007 – 2009; for example accident in 2008 was linked with the expected volume in 2008. The sections with no accidents were assigned the volume in 2007. This correction was made according to the Czech technical guidelines TP 225 (Bartoš *et al.*, 2010).

4.4 Calculation of accident frequency

To quantify the relationship between road width and safety, accident frequency (AF) was used. It is defined as follows (see eg. Hauer *et al.*, 2002):

$$AF = \frac{N}{L \cdot Y}$$

where N is number of injury accidents on the section, L is length of section [km], Y is duration [year].

To illustrate the calculation, if 2 injury accidents happen at 500m section between 2007 and 2009 (3 years), the accident frequency is:

$$AF = \frac{2}{0.5 \cdot 3} \approx 1.3$$

It means that approximately 1.3 injury accidents per 1 km and 1 year may be expected at similar section, ie. with similar traffic conditions such as speed limit or traffic volume.

5 RESULTS

As it was mentioned in chapter 4.3, road sections were grouped according to traffic conditions – see Tab. 3. For each row in the table null hypothesis was assumed. For example null hypothesis 1 assumes that distribution of AF on 9.5m roads in urban areas for total volume is equal to distribution of AF on 11.5m roads in urban areas for total volume.

Tab. 3 List of groups and numbers of assigned null hypotheses

number of null hypothesis	group 1			group 2		
	width	area	volume	width	area	volume
1	9.5 m	urban	total	11.5 m	urban	total
2			standard			standard
3			high			high
4		rural	total		rural	total
5			standard			Standard
6			high			high

The statistical standard is to use Student's t-test to compare variable means which is however applicable for normal distribution only. The number of accidents and their frequency are typically considered to have negative binomial distribution (see eg. Lord and Mannering, 2010). Therefore Mann-Whitney U test was chosen, being an alternative to Student's t-test applicable for other distributions. It was used to test difference between distributions of group 1 (9.5m road sections) and group 2 (11.5m road sections). Null hypothesis assumed that both group have equal distributions. Results are listed in Tab. 4.

Tab. 4 Values of accident frequency and related test characteristics

	number of null hypothesis											
	1		2		3		4		5		6	
group	1	2	1	2	1	2	1	2	1	2	1	2
sample size	1921	809	1435	478	487	331	3317	2484	2724	1491	596	985
AF mean	0.08	0.18	0.02	0.20	0.27	0.16	0.07	0.13	0.04	0.12	0.21	0.13
AF variance	0.94	5.49	0.07	8.11	3.52	1.72	0.55	1.77	0.44	1.83	2.29	1.66
significance	0.272		0.081		0.376		**0.022**		0.072		**0.051**	
result	null hypothesis retained		null hypothesis retained		null hypothesis retained		**null hypothesis rejected**		null hypothesis retained		null hypothesis retained	

All but one hypothesis were retained – their differences are not significant. The only significant difference is under the fourth hypothesis, ie. between 9.5m and 11.5m rural roads at total traffic volume. The significance of sixth hypothesis is 0.051 which is practically almost at the level of null hypothesis rejection (p = 0.05) as well.

6 CONCLUSIONS AND DISCUSSION

According to results of statistical tests it can be stated that there is no difference between AF on urban roads (null hypotheses 1, 2, 3 were retained); however there is a difference between AF of 9.5m and 11.5m rural roads at total and high volume (null hypotheses 4 and 6 were rejected).

The observed difference has two aspects:

1) At total volume the difference between AF means on 9.5m and 11.5m rural roads is almost twofold (0.07 vs 0.13).
2) Results are opposite at rural sections with high volume only: their AF at 9.5m sections is higher that at 11.5m sections (0.21 vs 0.13).

The reason of difference (1) may lie in insufficient safety culture in the Czech Republic, which causes more speeding and overtaking related accidents on wider roads.

The result (2) falls in line with finding of Hauer (2000) who states that shoulder width is more beneficial to safety at higher traffic volumes than at lower ones. He sees the whole relation as sum of a number of conflicting tendencies, including beneficial recovery area provision. This is also mentioned provided by Stein and Neuman (2007) among the safety functions of shoulder: shoulders may increase safety by providing a recovery area for drivers who have left the travel lane while attempting to avoid a crash or an object in the lane ahead. All these opposite tendencies may cause the above mentioned inconsistency.

To sum up, relation between road width and safety (in terms of accident frequency) was found to differ significantly on Czech 9.5m and 11.5m rural roads. It may be attributed to combination of speeding and overtaking (more frequent at 11.5m roads) and being provided less recovery space (typical at 9.5m roads) at higher traffic volumes. These facts are in fact complementary and overlapping. It can be concluded that drivers behave the same way, regardless on the road width, however they have less space for overtaking and recovery manoeuvres at 9.5m roads.

All these assumptions need to be checked and assessed by further research. Future studies might also consider other traffic conditions to set the categories to be tested. The ultimate solution would be developing accident prediction model, taking into account more variables in order to describe the traffic conditions in more complex way. All these data are contained in road passport introduced in chapter 3. Such a model should use equal length of sections and predict expected number of accidents. It could also differ between accident severity, type of road (motorways, expressways…) or geometric variables of the road.

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