TØI report 840/2006
Authors: Peter Christensen
Arild Ragnøy
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Summary:

The condition of the road surface and safety

The importance of rut depth, roughness (IRI) and changes in cross-slope for road safety

Background and research problem

In 2002, a study (Ihs, Velin og Wiklund, 2002) was published by VTI (Swedish Road and Transport Research Institute) that investigated the relationship between the road surface, more specifically rut depth and roughness measured by IRI (International Roughness Index), and accidents. The main results of the report, ”Vägytans inverkan på trafiksäkerheten” (”The importance of the road surface for road safety”), was that increased rutting reduces and increased IRI increases the risk of accidents.

These results came as a surprise for Norwegian experts, in particular the reduced accident risk when rutting increases. The Institute of Transport Economics was therefore commissioned by the Norwegian Public Roads Administration to undertake a study of the relationship between rutting and accidents. A critical review of the Swedish report was considered a part of the study. However, the Public Roads Administration was also interested in the importance of IRI and variations of cross-slope for accidents. The objective of the study described in this report has therefore been to investigate the relationship between accidents and rut depth, IRI and variations in cross-slope. The analysis of rut depth has, however, taken priority.

Methodological approach

The accident risk on a road depends on many other factors than rut depth, IRI and changes in cross-slope. It is therefore necessary to control for the effect of other variables when studying the relationship between accidents and rut depth, IRI and changes in cross-slope. The standard method for doing this is regression analysis. An alternative method is to control for the difference between roads not by comparing different roads but by exploiting the fact that both rut depth an IRI evolves and therefore a road has different values at different times. This method has been named “Internal comparison” because the number of accidents is only compared with the number of accidents on the same road at a different time.

For each section of road there were six years of data. Internal comparison was carried out in two different ways. One way was to rank the six years by rut depth

and check whether the number of accidents increased by rut depth. The other was to class rut depth by intervals and require that rut depths in two given intervals should be found on one road section in different years. For example, when comparing rut depths in the intervals 0-4 mm and 4-9 mm only road sections where rut depths in both intervals were found were used in the comparison. Equivalent requirements were made for comparing 0-4 mm to 9-15 mm, etc.

Source of data

The study utilises data for six years, the period from 1998 to 2003. The source of all data is the Road Data Bank. In addition to data for accidents, rut dept, IRI and cross-slope we received data for curve radius, average annual daily traffic (AADT), percentage long vehicles (as a proxy for heavy vehicles), speed limit, gradient and road width. Data for rut depth, IRI and cross-slope is given lane-wise and each lane is considered separately. An effort has been made to place accidents in lanes, as well (see below). This is not possible when there are more than two lanes. Therefore, roads with more than two lanes are excluded from the study.

Data for ADT, percentage long vehicles, speed limit and road width pertains to both lanes. Gradient is also given for the road and not per lane. However, this pertains to the direction in which the length of the road is measured, ie lane 1. The gradient in the other direction has the opposite sign. The absolute value of the gradient has been used in the analyses.

Data for road attributes that may change over time are given for each year. This pertains to all data except for the gradient and road width. These data were given once for the whole study period and assumed valid for the whole period.

Only national roads were included in the study, ie county roads and municipal roads were excluded.

Rut depth, IRI and cross-slope have been measured for road sections of various lengths. Most sections are 20 m or close to 20 m but they may be shorter or longer. Since data for several years is used for rut depth, IRI, cross-slope and other variables, it is advantageous if the same road sections are defined each year. It is essential for the internal comparison described above. However, the 20 m sections measured are not necessarily the same every year. The starting point may vary by 10m, ie the starting point one year may be in the middle of a section in another year. It was therefore decided to generate 100 m sections with the same start and end points every year.

To generate the 100 m sections the shorter sections had to be split and rejoined: Both rut depth and IRI for the 100 m section were calculated as the weighted average of the bit of sections comprising it, weighted by the length of the bits. The change in cross-slope for the 100 m section was defined as the difference between the largest and smallest cross-slope for the bits of sections included.

Special programmes to generate the 100 m sections were written (in the C programming language).

Accidents at crossings where excluded from the analysis. Accidents are placed in a lane depending on which lane road-users were in when the accident happened. However, the register of accidents which is the basis of our data does not have information on the lane in which road-users were moving but in which direction they were travelling. Directions were indicated as from the North, from the North-East, etc. To decide the lane in which the road-user was moving it is therefore necessary to know the direction of the road where the accident took place.

The direction of the road could be determined by an electronic road map (ELVEG). For each accident the coordinates are used to determine the direction of lane 1. For a number of accidents lack of coordinate information precluded the determination of the direction.

Unfortunately, there was far from perfect agreement between the direction of the road as determined from ELVEG and the direction road users were travelling. The principle for placing road users in lanes was as follows. If the direction of the road was towards the North, road users (with the exception of pedestrian) that travelled towards the Northwest (ie coming from the Southeast), towards the North or towards the Northeast were regarded as travelling in lane 1. If they were travelling towards Southeast, towards the South or towards the Southwest they were regarded as travelling in lane 2.

If the direction of travel was stated as towards the East or towards the West it is not possible to decide in which lane they were travelling. For this reason more than 5000 accidents had to be left out because they could not be placed in a lane.

Given the lane that road users were travelling before the accident, the lane in which the accident is placed is decided on the following principles.

- Single vehicle accidents are attributed to the lane in which the road user was travelling
- Accidents where the road users travel in the same direction (rear end accidents) are attributed to the lane where they were travelling.
- Head-on accidents are counted as 0.5 accidents in each lane for the internal comparison so that the number of accidents is correct. For the regression analysis head-on accidents were counted as one in each lane.

Results

Regression analysis

The unit in the analysis is a 100 m section in one lane in one year. Very few of these units had more than one accidents. The dependent variable in the regression analysis was therefore whether there had been an accident on one unit or not. This calls for the use of logistic regression.

Logistic regressions were performed both with AADT entered linearly and where a logarithmic transformation of AADT was used. In the first case it was found that the coefficient of rut depth was statistically significant, and in second case it was not. This does not necessarily mean that rut depth does not affect the accident risk. It may just mean that the relationship between rut depth and the accident risk (more correct: the logit of the probability of an accident) is not linear. By categorising rut depth in five groups, 0-4 mm, 4-9 mm, 9-15 mm, 15-25 mm and above 25 mm, the effect of rut depth can be analysed by four dummy-variables that express the increase in logit relative to the 0-4mm group.

The results from the logistic regression are shown in table S1. The regression also included dummy-variables for counties and for different speed limits. The coefficients of these variables have been left out in table S1 to avoid a too large and cluttered table.

Table S1. Results from the logistic regression. The dependent variable is a dichotomous variable indicating whether there has been an accident or not. The number of units: 2098940. The number of units with an accident: 10721.
*: Significant at the 10%-level, **: Significant at the 5%-level, ***: Significant at the 1%-level.

	Coefficient	Standard deviation	Significance level	
Rut depth. 4-9	0.1677	0.0583	0.0040	***
Rut depth. 9-15	0.1031	0.0589	0.0800	*
Rut depth. 15-25	0.1229	0.0616	0.0462	**
Rut depth. >25	0.2212	0.1020	0.0301	**
Cross-slope	0.0092	0.0040	0.0225	**
Curvature	128.8130	5.0030	0.0000	***
IRI	-0.0343	0.0127	0.0069	***
Dummy, EV	-0.0414	0.0273	0.1300	
Ln(AADT)	1.0232	0.0152	0.0000	***
% long vehicles	0.0041	0.0029	0.1576	
Mean gradient	0.0053	0.0058	0.3571	
Road width	-0.0136	0.0049	0.0055	***
Constant	-14.0051	0.2805	0.0000	***

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Comparison of accidents on the same section in different years

Comparison of accidents on the same section in different years (internal comparison) was, as described above, carried out in two different ways. The first method, ranking of the measured values found no relationship between rut depth and accidents or between IRI and accidents. A possible explanation for the negative result is that the method is not sufficiently sensitive to demonstrate a relationship. There are large differences between rut depths and IRI values for different sections. The largest rut depth on one section may be smaller than the smallest on another.

By categorising rut depths into intervals this problem is avoided. All comparisons are between intervals. This ensures that the rut depths compared do not vary too much.

With 5 categories there are ten possible pair-wise comparisons. The comparisons are partly independent because the road sections included in the comparison between 0-4 mm and 4-9 mm are not necessarily the same that are included in the comparison between 0-4 mm and 9-15 mm. If they are treated as independent (as an approximation) the ten pairwise comparisons can be used to estimate four parameters. Let f_1 denote the relative increase in accident rate from category 0-4 mm for rut depth to the category 4-9 mm for rut depth, ie the ratio of accident risk in category 4-9 mm and 0-4 mm. Equivalently, denote by f_2 the relative increase from 4-9 mm to 9-15 mm, f_3 the relative increase from 9-15 mm to 15-25 mm and f_4 the relative increase from 15-25 mm to more than 25 mm. The four parameters can be determined by weighted least squares. The accident rates for the categories 5-9 mm, 9-15 mm, 15-25 mm and more than 25 mm may then be expressed relative to the category 0-4mm. This is shown in figure S1. The figure also shows confidence intervals for the relative accident rates. These confidence intervals are only approximate and should be considered as a lower bound.

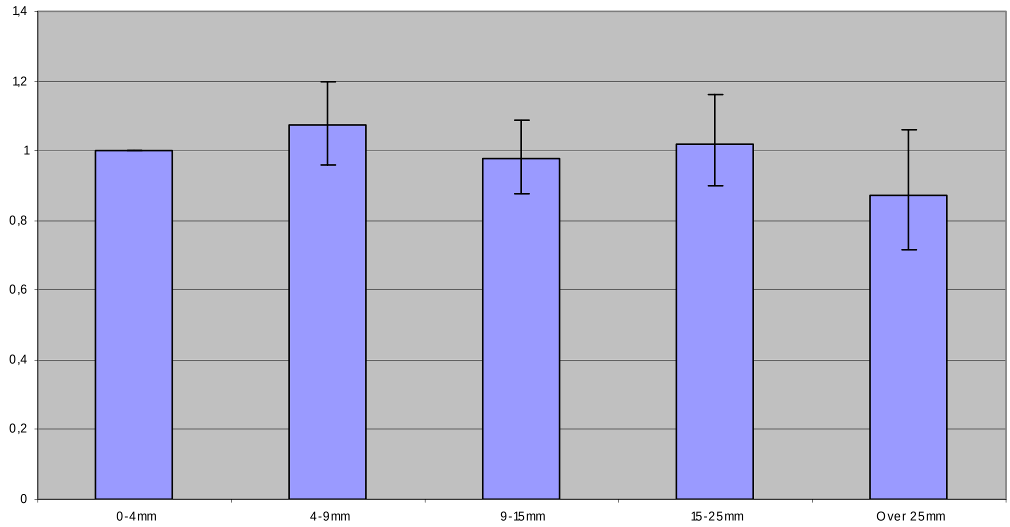

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Figure S1. The relative accident rates for different categories of rut depth. The accident rate in the category 0-4 mm has been set to 1. The lines indicate an approximate 95% confidence interval.

This analysis finds no clear relation between rut depth and accident rate. Of the ten comparisons behind figure S1, only one showed one significant difference and there are no significant differences between the relative accident rates in figure S1, all confidence intervals include 1. However, the pattern shows some similarity to the result from the regression analysis presented in table S1, where AADT was transformed logarithmically, except for the category with rut depth above 25mm,. This gives some support to the choice of a logarithmic transform of AADT. The figure does definitely not show the linear increase of risk rut dept that was found with a linear AADT.

Conclusions

The regression analysis shows that increased rut depth entails an increased accident risk. Regression analyses of subcategories of accidents found the same increase for most categories of accidents, though the increased risk was not significant in all cases. When both head-on and single vehicle accidents are left out, the increase of accident risk with rut depth is no longer significant.

From the regression analysis can also be concluded that there is a negative linear relation between IRI and accident risk. An increase in IRI entails a reduced accident risk. The coefficient of IRI was negative and significant for the large majority of subcategories of accidents.

For some subcategories of accidents, the larger the change in cross-slope the higher the accident risk. This pertains to accidents during the winter but not to accidents during the summer. This pertains to single-vehicle accidents but not to head-on accidents. It is also the case when all accidents are included.

Comparison of accidents on the same section in different years does not find an equally clear relation between rut depth and accident risk. However, this method does not correct for the effect of IRI like the regression analysis does. It may therefore underestimate the effect of large rut depths since a large IRI will also be common in this case.

The results of this study are the opposite of what was found in Sweden. The Swedish study found that increased rut depth reduces the accident risk while increased IRI increases it. Here we find that increased rut depth increases the accident risk while increased IRI reduces the accident risk. Whether the difference is real or due to methodological problems in one or both studies is currently unclear.

Implications of the results

Employing the results from the logistic regression, some examples have been produced to indicate the practical importance of the relationship between accidents and the other variables. As a simplification the relationships can be expressed as approximately linear relationships. This simplification is made so that the results will be easier to apply for practical purposes.

Bivariate relationships are shown between relative accident risk and rut depth, IRI and change in cross-slope respectively, ie the relationship is given keeping all other variables than the one varied constant. When rut depth increases by 1mm (and all other variables are constant) the accident risk is increased by 0.6%. When IRI increases by 1mm/m the accident risk is decreased by 3%. An increase in the change in cross-slope leads to an increase in accident risk.

Table S2. Simultaneous evolution of rut depth and IRI for a road with AADT=1000.

Year	1	5	10	15	20	25	30
Rut depth mm	2.50	7.38	13.48	19.58	25.68	31.78	37.88
IRI mm/m	1.74	2.02	2.36	2.71	3.05	3.40	3.74

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After a road has been resurfaced both rut depth and IRI will increase with time. When the road surface is new, so-called initial values apply to rut depth and IRI. In the example shown in figure S2 initial values and the annual deterioration have been obtained from the Road Capital Project under the auspices of the Norwegian Public Roads Administration (not yet published). Accident rates and injury cost per accident have been obtained from the Optimal Maintenance of Roads project, also under the auspices of the Norwegian Public Roads Administration. Table S2 shows the simultaneous evolution of rut depth and IRI for a road with AADT of 1000 as rut depth and IRI increase from 2.5 mm and 1.74 mm/m respectively the first year to 38 mm and 3.74 mm/m after 30 years. Figure S2 shows the evolution of annual injury costs The horizontal line indicates the annual injury costs if there had been no deterioration of the road surface. The road safety potential of road resurfacing, ie the annual savings in accident costs, is the difference between the two curves in the figure.

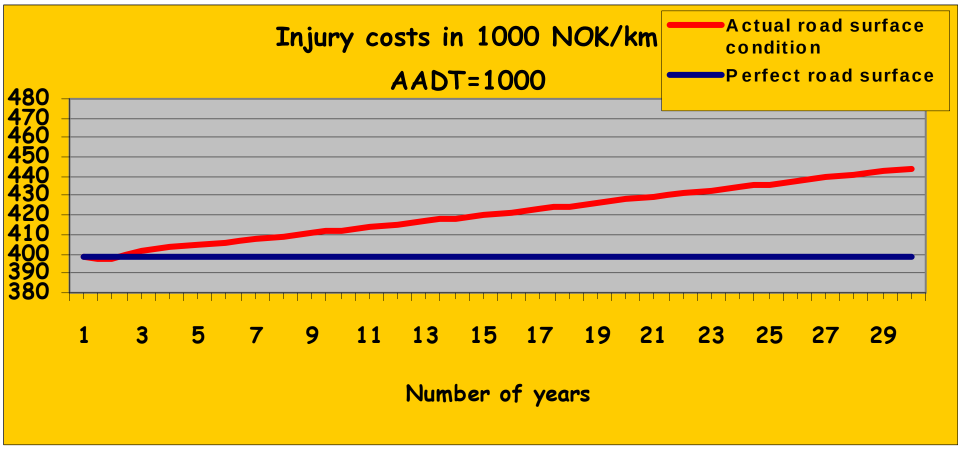

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Figure S2. Annual injury costs pr km road (AADT=1000) for the actual road surface condition and for a perfect road.

The safety potential and accumulated safety potential for selected number of years after resurfacing is given in table S3.

Table S3. Safety potential and accumulated safety potential for selected number of years after resurfacing.

Year	1	5	10	15	20	25	30
Safety potential in 1000 NOK/year	-	6	14	21	29	37	45
Accumulated safety potential in 1000 NOK	-	13	65	156	287	457	668

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As figure S2 and table S3 show, the road safety potential increases from zero in the first year to 14000 NOK/km after in year no 10. The accident reduction caused by increased IRI is more than compensated for by increased rut depth. Disregarding considerations of discounting, the annual savings shown in figure S2 may be accumulated so that at a certain time it will be cost-effective to resurface the road rather than to bear the accident costs.

This calculation is very sensitive to AADT. The road safety potential in the 10th year is 14000 NOK/km for a road with AADT 1000 but more than ten times larger, 147 000 NOK/km for a road with AADT 10000.