Safety evaluation of different kinds of cross-section on rural two-lane roads

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SUMMARY

The task was based on a literature search to review the safety features of different kinds of rural single carriageway cross-sections in different conditions.

The compilation of existing research results of the safety of different cross-section elements was difficult due to the differences in the accident types studied. Most of the studies used all accidents or personal injury accidents only, while some focused on certain accident types and differences of accident severities. Furthermore, the results were more often qualitative rather than quantitative.

Since roughly half of the accidents on two-lane rural roads are single-vehicle and head-on accidents, and in addition, half of the fatalities are caused by head-on accidents, there is a clear need for a detailed approach in analyses. Part of the research results support dividing all accidents into head-on, run-off and hit-fixed object accidents. Thus, it is possible to appoint the changes in accident risks as well as the changes in accident severities.

On rural two-lane main roads, where the physical upgrading of the road is realistic because of high traffic volumes, also the probability for multi-vehicle accidents is greater compared to lower traffic volumes. The research results indicate that the lane widths of 3.5–3.7 metres together with paved or stabilised shoulders totalling up to about 10 m provide effective lateral clearance and recovery area and thus, most likely benefit safety. Further pavement widenings may encourage to higher operating speeds and more careless driving. This can compensate the safety margin wide pavements provide, and possibly, result an increase in accident costs.

On other than main roads, where the standard of the road is poorer, the main focus is on single-vehicle accidents but also on opposite direction accidents. Single-vehicle accidents are usually a result of too high operating speeds for the design of the road. Research results support the view that widening the lanes may not be the right remedy, but rather an increase of in both the recovery and avoidance space. This could be achieved by stabilised shoulders and ‘forgiving roadside’ design. The latter includes, for instance, flatter sideslopes and obstacle-free zone.

Finally, it was concluded, that it would be more fruitful to consider cross-section factors together with alignment and roadside factors, rather than trying to determine the safety effects of individual cross-section elements.
# CONTENTS

SUMMARY .......................................................................................................................2

1 INTRODUCTION.........................................................................................................4

2 RESEARCH RESULTS OF THE INFLUENCE OF DESIGN PARAMETERS ON ACCIDENTS .................................................................................................................5

2.1 General .................................................................................................................5

2.2 Road width ............................................................................................................6

   2.2.1 Driving lanes ................................................................................................6

   2.2.2 Shoulder .....................................................................................................7

   2.2.3 Pavement ....................................................................................................9

   2.2.4 Redivision of pavement ...........................................................................10

2.3 Roadside design ..................................................................................................11

   2.3.1 Geometric design .......................................................................................11

   2.3.2 Fixed objects ............................................................................................12

3 DRIVING BEHAVIOUR .............................................................................................14

4 DISCUSSION OF THE RESULTS .............................................................................15

REFERENCES .................................................................................................................21
1 INTRODUCTION

Although the risk of a personal injury accident per kilometers driven is higher on urban streets, the risk of a fatal accident is higher on public roads. Furthermore, for instance, of Finnish public road accidents, about 70% of personal injury accidents and 80% of fatalities occur on two-lane rural roads. This is in accord with the results from other countries.

Rural two-lane roads will be required to play a more important role in the years to come. Along with meeting the new requirements, at the same time, a step towards better accident figures should be taken. In practice, a form of physical upgrading should answer for both needs.

On rural roads cross-section is very important for safety. There is some indication that the safety effects of the changes in cross-section might not clearly be discovered by focusing on the total number of accidents, while an effect could be detected when concentrating on certain accident types such as run-off-road, head-on and hit-fixed object accidents. The roadway variables possibly associating with these related accidents types include lane width, shoulder width and type, roadside condition, terrain condition and traffic volume. Also, the frequency of unprotected road users may have an effect on cross-section safety.

Furthermore, when looking at the injury accidents only, the differences of severity can easily bias the comparisons. For instance, on two-lane rural main roads in Finland, almost every second fatality is caused by a head-on accident, which is not the most common injury accident type (15% of injury accidents). Run-off road accidents is the most common accident type (30%), but it covers only 15% of fatalities on Finnish two-lane rural roads. Differences between injury and fatal accidents can be found from other countries as well.

Although there are many similarities in the studies concerning the safety effects of cross-section factors, also results that seem conflicting can be found. The aim of the task was to comprehensively review the safety features of different kinds of cross-section in various conditions of the single carriageway in rural Trans European Road Network (TERN). Here the main focus was on straight road sections. In Finland, for instance, the accidents and fatalities caused by single-vehicle and head-on accidents do occur on average slightly more often on straight road sections.

The task was based on a critical literature study and compilation of existing results of safety studies. Special attention was paid for severe accidents. Research methodological issues were focused, if necessary, in order to find out reasons to previous contradicting results.
2 RESEARCH RESULTS OF THE INFLUENCE OF DESIGN PARAMETERS ON ACCIDENTS

2.1 GENERAL

Safety considerations of cross-section design primarily consist of two goals: firstly to keep the vehicles on the roadway and to prevent crashes from occurring, and secondly to reduce the consequences after the vehicle runs off the roadway, that is, to reduce the severity of accidents.

The safety aspect is only one of the factors affecting cross-section dimensions but is of particular importance in the design practice. Moreover, cross-section width is affected by (Ruyters et al. 1994):

- Road network factors: road function, design speed;
- Traffic factors: traffic volume, width of passenger cars and heavy vehicles, number of pedestrians and cyclists;
- Road factors: alignment, drainage, number and function of traffic lanes and shoulders, construction practice, maintenance procedures;
- Human factors: drivers’ behaviour in speed and lateral position, behavioural adaptations;
- Environmental factors: landscaping, access requirements, aesthetics;
- Operational requirements: required level of service, capacity;
- Benefit/cost analysis: construction, maintenance, accident and operational costs.

Two-lane rural roads include many different types of road, ranging from traditional, winding roads to modern high quality roads with gentle curves and full cross sections. Even in some cases, two-lane roads with wide paved shoulders or wide lanes are used like four-lane roads. Thus, undivided rural roads can have considerable different dimensions of traffic lanes and shoulders, not to mention the variety of roadside characteristics.

Of the cross-section design parameters, only the concept of lane width is fairly unambiguous between different countries. Other design parameters, such as shoulder width and type or sideslope design, have fair amount of variation in design practice. For instance, in many cases, hard shoulders form part of the carriageway construction, but alternatively they may be only stabilised strips adjacent to the carriageway.

From the perspective of research method, the research results pointing out the effects of individual cross-section factors can have many weaknesses. The results are usually based on large-scale comparisons of different road environments, so called cross-sectional approach, and less frequently before-after with control site experiments. The cross-sectional approach, usually in the form of accident modelling, is suitable for determining the effect of many variables acting together. However, the conclusions made for the effects of individual factors should be
evaluated with care. Examining the relationship between single design factors and accidents without considering the interactive effect with other parameters can yield biased or masked relationships.

2.2 ROAD WIDTH

2.2.1 Driving lanes

An early Swedish study by Edholm and Roosmark (1969) indicated that the accident frequency was higher for carriageway\(^1\) widths of 6–6.5 m compared to 7–8.5 m. Inside these groups accident frequencies were quite stable.

A Danish study of 1976–78 accidents on different types of road led to the conclusion that the accident rate was lower on two-lane rural roads with carriageway widths of 7–8 m compared to those between 8–9 m and over 9 m (Vejdirektoratet 1980). Hereafter, for widths of 8–9 m and over 9 m, the accident rate resembled that of 7–8 m roads.

In Germany, there was carried out an extensive before-after study where 90 km of road was redesigned according to national guidelines (Hiersche et al. 1984). According to the regression analysis, the accident rate showed a decrease, but the accident cost rate increased with increasing carriageway width (figure 1). In most of the test sites paved shoulders were only adjacent strips.

![Figure 1. The effect of the carriageway width on the accident rate and the accident cost rate on German two-lane roads (Hiersche 1984).](image)

\(^1\)Carriageway in this report is used to indicate the width of driving lanes.
Other cross-sectional study in Germany (Brannolte et al. 1993) reported that among the regular two-lane types, cross section with a lane width of 3.5 m yielded comparative favourable values. Still narrower lanes led to clearly higher accident rates and accident cost rates. Driving lanes of 3.75 m had higher accident cost rate compared to 3.5 m, even though there were no notable differences in accident rates.

In the 1970’s in the USA Zegeer et al. (1979) found that accident rates for all accidents, run-off-road and opposite-direction accidents generally decreased as lane widths increased. 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 in part the limit beyond which further increases in lane width were ineffectual.

Later 1987, Zegeer et al. quantified the effects of lane width (also shoulder width and type) on highway crash experience based on an analysis of data for nearly 8000 km of two-lane highway from seven states. It was also concluded that the accident types found to be most related to cross-section features include run-off-road, head-on and sideswipe (same and opposite direction) accidents. Lane widening of 0.3 m was found to reduce these related accidents by 12%, 0.6 m by 23%, 0.9 m by 32% and 1.2 m by 40%. There was found no definite relation between lane (or shoulder) width and accident severity. The results concluded to be valid for two-lane rural roads with lane widths of 2.4 to 3.7 m and traffic volumes of 100 to 10 000. The study was reported to control for many roadway and traffic features, including roadside hazard, terrain and average daily traffic. However, to fully eliminate the effects of all other safety affecting variables is quite impossible, and therefore the effects of increased lane width may be overestimated.

Furthermore, according to Zegeer et al. (1995), the same percentage of accidents was reduced for a given amount of lane (or shoulder) widening, regardless of the situation before. Zegeer et al. though reminded that the predicted accidents reductions given above were valid only when the roadside characteristics (sideslope and clear zone) were re-established as before the lane (or shoulder) widening.

2.2.2 Shoulder

A road shoulder serves, with operational and safety purposes, a number of functions, including e.g. (Armour & McLean 1983):

- Increases the effective width of the traffic lanes and so increases lateral clearance,
- Provides a recovery area for errant vehicles,
- Provides space for slower vehicles to allow faster vehicles to overtake,
- Allows a stopped vehicle to stand clear of the traffic lanes.

In general, there is no agreement in EU countries on the paved shoulder width of non-motorways. Non-motorways do not necessarily have shoulders or they have wide paved shoulders which causes the pavement width usually vary from 7.5 m to 11.5 m. This partly reflects the fact that there is no consensus on the safety effects of the shoulders.
A Swedish study in 1960’s (Edholm & Roosmark 1969) indicated that paved shoulders were beneficial in safety aspect at carriageway widths of 6 metres (1 m shoulder) and 7 metres (<2 m and ≥2 m shoulders) and with all traffic volumes. The safety potential was bigger with higher volumes. There was no statistical difference between 7 m carriageway without shoulder and with 1 m shoulder. Furthermore, there was no extra benefit from 3 m shoulder compared to 2 m.

A Danish study (Vejdirektoratet 1984) concluded that for carriageway widths of 6.5 to 8 m, a paved shoulder increase from 0.2 m to 0.5 m showed a significant reduction of accident risks for vehicle accidents by about 25 % and for pedestrian and cycling accidents by 40 %. Effect of further increase in shoulder width (≥ 0.9 m) was uncertain, but indicated no effect on vehicle accidents and possibly a further reduction of 20% in pedestrian and cycling accidents.

In Germany, Brannolte et al. (1992) detected that two-lane roads with shoulders had about 10% lower accident rate and about 10–17% lower accident cost rate for personal injury and severe property damage accidents compared to similar roads without shoulders. The difference in accident cost rate was greatest when turning and crossing accidents were included in the comparison.

In the USA, Foody and Long (1974) found that mean accident rate for stabilised shoulder sections was significantly less than for sections of unstabilised shoulders. Particularly, the results indicated that shoulder stabilisation or paving was quite effective in reducing run-off-road accidents on narrow roadways, typically 6 m or less in width, but had only little effect on roads widths of 7.2 m or more.

Based on a sample of over 3000 individual rural two-lane roadway sections of North Carolina primary roads, a significantly lower accident experience and accident severity index were associated with various types of highways with 0.9 m and 1.2 m paved shoulders, when compared with the similar highway counterpart with unpaved shoulders (Heimbach 1974).

In Australia, Armour and McLean (1983) concluded that paved shoulders had better safety records than unpaved shoulders for a wide range of traffic volumes and shoulder widths. The accident savings from improved shoulder design was reported to mainly result from reductions in run-off-road and opposite-direction accidents.

In Australia, according to the primary safety function, paved shoulders provide a greater recovery and manoeuvring space. Paved shoulders reduce the potential for vehicles which stray from the paved driving lane to lose control in loose shoulder material (Catchpole 1990). Armour (1984) found this to be a contributing factor in over 50% of fatal run-off-road accidents in New South Wales, while Catchpole (1990) concluded that at least 19% of single-vehicle accidents at sites with paved driving lanes and unpaved shoulders involved a driver losing control of the vehicle in the shoulder.

On two-lane rural roads in Australia there was carried out a before-after study with a control group in order to investigate the effects of shoulder paving (Ogden 1995). A typical cross-
section had a carriageway width of 7.4 m where there were added 0.6–0.8 m paved shoulders on each side to give a 8.6 or 9 m pavement. Control sections were similar in standard, alignment, terrain, roadside conditions and traffic flow, and geographically close to the analysis sites. The accident counts were fairly small (about 100 accidents on both study and control group), but showed a significant reduction on personal injury accidents. Reductions were appointed to rear-end, overtaking - out of control, off carriageway to left, and off carriageway to right into fixed objects accidents.

In the USA, Rogness et al. (1981) concluded that roads with shoulders have 30% less accidents compared to roads without shoulders. Later, with a more detailed approach, Rogness et al. (1982) concluded that at low volumes (ADT <3000 veh/d), there were significantly fewer single-vehicle accidents, indicating the effectiveness of the paved shoulder in providing recovery space. At moderate volumes (3000–5000 veh/d), the addition of paved shoulders reduced both the total number of accidents and their severity, suggesting that the shoulders were being used for both accident avoidance and recovery. At higher volumes (5000–7000 veh/d), again accident frequency was reduced, but there was an increase in severity of those that did occur. This was attributed to increasing operating speeds. Overall, no significant reductions were found for head-on accidents.

Zegeer et al. (1979) found that accident rates for all accidents, run-off-road and opposite-direction accidents generally decreased as shoulder widths increased. In a later study Zegeer et al. (1987) quantified that widening paved shoulders by 0.6 m reduced these related accidents by 16%, 1.2 m by 29%, 1.8 m by 40% and 2.4 by 49%. For unpaved shoulders the effects were 13%, 25%, 35% and 43%, respectively. The results were valid for two-lane rural roads with lane widths of 2.4 to 3.7 m, shoulder widths of 0 to 3.7 m and traffic volumes of 100 to 10000. However, to fully eliminate the effects of all other safety affecting variables is quite impossible, and therefore the effect of increased shoulder width may be overestimated.

2.2.3 Pavement

From the 1970’s in Sweden, there are studies (Brüde & Nilsson 1976, 1977) of the accident rate in different road environments. For all 90 km/h roads the accident rate decreased with paved width up to about 10 meters. For further pavement increase, the accident rate increased in the poorest alignment class.

In Great Britain, Hughes and Amis (1996) concluded that one metre increase in carriageway width was connected with a 19 per cent decrease in accidents. The carriageway is defined differently in different countries. In some countries carriageway comprises all the paved width, as in some countries only the driving lanes.

In Finland, Peltola (1995) concluded that on main roads the risks for personal injury and fatality appeared to be lower on wider pavements (medium wide: 8.1–9 m, wide: over 9.5 m). The result was the same for ADT’s over and under 6000 vehicles per day. However, on other than main roads the risk of fatality seemed higher on wider pavements (medium-wide: 6.6–7 m,
wide: over 8 m). Increase in risk was appointed to more severe single-vehicle, overtaking and head-on accidents. The differences in risks of were larger at lower traffic volumes (ADT<1500 veh/d).

Accident prediction models developed in Finland (Roine & Kulmala 1991) are based on a finding that the effect of pavement width on the number of personal injury accidents is affected by traffic volume and hilliness of the road. If the road is very hilly (> 30 m/km), the relative accident risk on wider pavements (pavement width $\geq 8.6$ m) is smaller than on narrower roads only with greater traffic volumes. If the road is flatter, the relative accident risk is usually smaller on wider pavements. To conclude, widening the road does not appear to give favourable safety effects on hilly roads and with low traffic volumes.

Accident prediction model of Cleveland et al. (1984) lacked a strong independent safety effect of pavement or shoulder width for rural two-lane highways carrying fewer than 3 000 vehicles per day.

Pavement edge drop-offs has not largely been discussed in the literature. However, it probably is a contributing factor in driver loosing control after leaving the travel lane. Depending on the angle of the vehicle departure and the driver’s level of surprise, several outcomes are possible (Glennon 1987). For instance, with high departure angles the vehicle will enroach the roadside, but with smaller angles the driver response determines the outcome. The vehicle can safely recover to the driving lane, but also, after a high re-entry angle, to roll over or cross to the lane of oncoming vehicles. According to Glennon, the probability of a successful recovery decreases as the drop-off face approaches a full vertical edge, the drop-off height increases, the vehicle speed increases and the lane width decreases.

### 2.2.4 Redivision of pavement

Since the year 1989 Sweden has carried out studies of wide, 13 meter, two-lane road where the lane width is typically 5.5 m (before 3.75 m) and hard shoulder width 1 m (before 2.75 m). The earlier safety results (Brüde & Larsson 1994) indicated that the severity of accidents increased strongly in connection with the widening of the road on typical two-lane rural roads. This was valid for both single-vehicle accidents and multi-vehicle accidents. The accident rate for personal injury accidents was also found to increase compared to the control group (58 ± 43%). About the driver behaviour, Swedish studies stated that with wider lanes the dispersion of traffic across the road varied to a greater extent (Centrell & Gustafson 1995).

Later on, with a more extensive test material, Brüde and Larsson (1996) concluded that the accident rate, injury consequence and injury rate were almost the same for roads with and without wide lanes. Furthermore, there were no differences in the severity of accidents. However, wide lanes had a larger proportion of single accidents but fewer rear-end, turning and crossroad accidents.

In Germany, Brannolte (1993) has also studied the effects of overwide rural road with 5.25 m lane width. Compared to a typical 3.75 m (or 3.5 m) lane width and 2 m (1.5 m) unpaved
shoulder (e.g. grass verge), the accident rate and accident cost rate were higher on overwide road. On overwide roads, slightly more accidents occurred on daylight and on dry road surface compared to more night time accidents on typical two-lane roads.

Earlier quoted studies agree that widening driving lanes over 3.6–3.7 m does not necessarily reduce the accidents. It would appear, therefore, that wide lanes are not beneficial in terms of road safety.

Redivision of pavement could also be done by widening the shoulders by narrowing the driving lanes. Research results on the issue have not been found.

2.3 ROADSIDE DESIGN

Roadside can be defined to begin from the outside shoulder edge. Roadside design includes the design of the hinge point, foreslope, ditch or drainage channel and backslope.

Roadside features are, strictly speaking, severity-increasing rather than causative factors in run-off-road accidents (Harwood et al. 1994). The cause of an accident is the vehicle, driver or roadway factor, or combination of factors that causes the vehicle to leave the roadway and enroach the roadside. The characteristics of the roadside affect the ability to regain control of a vehicle which has run off the roadway, and the severity of accidents that occur.

‘Forgiving roadside’, which could be achieved by good geometric design and an obstacle free zone, is important when considering the fact that in EU countries about every third accident on interurban roads involves a vehicle leaving the carriageway (ERFS 1996). Moreover, most of the run-off road fatalities occur inside the road shoulder and the backslope of the ditch.

2.3.1 Geometric design

In the USA, flatter sideslopes of 3:1 to 7:1 have been found to relate to lower rates of single-vehicle accidents (Zegeer et al. 1988b). However, only a marginal reduction in single-vehicle accidents was found for a 3:1 sideslope compared to a 2:1 sideslope. Flattening a 2:1 sideslope to 7:1 or flatter was found to reduce single-vehicle crashes up to 27 percent (Zegeer & Council 1995).

The steepness of the foreslope also affects the likelihood that a vehicle that has run off the road will roll over. Tire-soil forces are the probable tripping mechanism in most slope and ditch rollovers (Viner 1995). Mechanisms contributing to tire-soil forces include the rate of slope, slope changes, soil cover and tire plowing in soft soil.

Rollover crashes are known to be severe, with most occurring on the roadside. Viner (1995) stated that the risk of a driver fatality or severe injury was greater in rollover than in any non-rollover crash type examined in Illinois. The rollover was involved in every second rural roadside fatality. Sideslopes and ditches were found to be the vehicle tripping mechanism in 70%
of rural rollovers. Another study of Zegeer et al. (1992) has stated that sideslopes of 5:1 or flatter were needed to significantly reduce the incidence of rollover accidents.

Roadside rollovers increase with speed (Viner 1995). Vehicles in single-vehicle run-off-road crashes were much more likely to overturn than vehicles that left the road in multi-vehicle crashes. Collision with other vehicles reduces speed and thus overturn risk in later collision events.

For drainage, ditches are not recommended for safety reasons, but wide shallow troughs are preferred (ERSF 1996).

2.3.2 Fixed objects

In most of the European countries approximately one quarter of all casualties is killed in accidents with obstacles (Ruyters et al. 1994). Obstacles by the roadside (e.g. columns and trees) affect the accident risks and especially the consequences of accidents. The safety effect of fixed objects can be evaluated by crash characteristics and lateral distance to objects (clear zone).

On road shoulders, the objects most often hit are guard-rails (e.g. Mäkinen & Roine 1990). Typical objects hit outside the shoulder are stones, rocks, trees and utility and light poles. Zegeer et al. (1988b) has further concluded that obstacles associated with the highest percent of severe accidents include culverts, trees, utility and light poles, bridges, rocks and earth embankments.

In Sweden, Schandersson (1979) examined the accident cost index of run-off-road accidents by objects being hit. The objects causing the most severe accidents included trees and culverts. Severe accidents were also caused by stones, rocks, rock cuttings and building walls. Pole and guard-rail accident cost indexes were only a little above mean of all run-off-road accidents.

In Finland, Ehrola (1981) compared the severity indexes of run-off-road accidents by objects being hit. He found that the severity index of hitting a guard-rail was only about half of the severity indexes of the most severe accidents. Severity index of hitting a utility or light pole was even slightly under that.

For rural fixed object impacts in Illinois (Viner 1995), the average rollover rate was 8.1%. Culvert headwalls posed the greatest overturn risk with a rollover rate of 27.6%.

In Finland, the risk of hitting a roadside structure has been found to be higher than average on roads with higher speed limits (80 to 120 km/h) (Kallberg 1994). In collisions with columns and bridge supports the initial speed was more than 70 km/h in over 90% of the accidents and more than 90 km/h in about half of the accidents. In every third of these accidents the vehicle turned over.
With higher speeds, the angle for vehicle departure and the lateral distance from the pavement has been found to be smaller compared to lower speeds (Schandersson 1985).

Ehrola (1981) suggests 15 meters for a critical distance from the edge of the road because practically all the accidents occur inside that zone. Obstacles in examined run-off-road fatalities were usually relatively close to the edge of the pavement. Elsewhere, Hedman (1990) concluded that a clear zone of 7 to 11 m for vehicles leaving the roadway at large angles and high front slopes, and 4.5 to 7 m for small angles and low front slopes, would be sufficient in most cases.
3 DRIVING BEHAVIOUR

In order for geometric improvements to reduce risks, roads should be adapted to the perceptual and behavioural performance of the road users. Some newly implemented road improvement schemes report changes in driving behaviour, but fall short of the effects on safety.

On wide-shoulder two-lane roads there is usually capacity for four vehicles abreast, if both the vehicles overtaken move aside on the shoulder. A Finnish study concluded that on wide-shoulder 12 m roads drivers accepted clearly shorter distances to oncoming vehicles, when deciding to pass the vehicle in front, than on typical 7–8 m two-lane roads (Kaistinen et al. 1992). Drivers were said to count on other and especially oncoming vehicles to give way if necessary.

In Sweden, overtaking behaviour has been studied on 13 m wide-shoulder roads (3.75 m lane, 2.75 shoulder) with high and low traffic volumes (Carlsson 1991). The aim of the study has been to determine how overtaking and passing behaviour is affected by road width. On 13 m roads, 85% of the vehicles moved to the paved shoulder when caught up. Three vehicles abreast, which means that meeting occurs at the same time as passing, was not unusual. At most, that occurred in 66% of all passings at high traffic flows.

A Finnish study (Pajunen 1997) indicated that on wide-lane (lane width 5.25 m compared to earlier 3.75 m) semi-motorways mean speeds of light vehicles were 3–5 km/h and heavy vehicles 1–3 km/h higher than before lane widening. The percentage of short (0–1 s) headways was two to three times bigger on wider lanes. These results are in agreement with a previous Finnish study (Saastamoinen 1994).

Zegeer et al. (1994) has pointed out that lane widths should produce operating speeds compatible with the selected design speed. Wider lanes with relatively low design speeds (≤ 80 km/h) may promote operating speeds above those for which the alignment was intended to accommodate.

On a wide road the objects along the roadside can also be farther off, which causes the same operating speed on a wide road to seem lower than on narrower road.
4 DISCUSSION OF THE RESULTS

Recent years numerous studies have been conducted to determine the effects of lane width, shoulder width and shoulder type on accident experience (table 1). However, many of them have focused solely on one aspect of the design and only few have been able to control for roadside condition (e.g. clear zone, sideslope), roadway alignment and other factors which, together with lane and shoulder width, influence accidents. Relationships of this kind can be masked or biased.

Moreover, studies have weaknesses, such as quantifying the total accident experience and not the related accidents, or the model presented explain poorly the variance in accidents. Since nearly half of the accidents on two-lane rural roads are single-vehicle or head-on accidents, and nearly half of the fatalities are caused by head-on accidents, there is a clear need for a more specific approach in order to find preventative measures.

However, when establishing a relationship between an accident type and a particular site feature, one might fall into false notion. For instance, the relationship perceived may not reflect the true effect of the site feature, but reflects the ADT values that tend to be associated with that site feature. Single vehicle accidents have been found to form a higher proportion of accidents where ADT is low than where ADT is high. This follows logically from the fact that low ADT reduces the opportunity for multi-vehicle accidents to occur. Also, low ADT values may reduce the driver workload too much causing fatigue. Other features associating with low ADT’s, and thus, single vehicle accidents, include lack of street lights, narrow lanes, lack of shoulders, sight restrictions, and based on the previous, relatively high speed limits.

The overall result of the individual research results could be reduced to an ‘ideal picture’ of a cross-section: wide enough lanes and paved shoulders, fairly flat and stabilised sideslopes and sufficient object-free zone. In practice, the question is more of a determining what is ‘wide enough’ and ‘sufficient’ from the safety aspect for particular conditions. There is indication that beyond some limit further improvements in cross-section might lead to higher operating speeds which are too high for the overall design of the road.

It is easily believed that roadside improvements lead to less severe run-off road accidents. However, it has been stated that most of the fatalities are caused by head-on accidents which in turn are not so directly affected by roadside design.

On rural two-lane main roads, where the upgrading of the road would be realistic because of high traffic volumes, also chances for multi-vehicle accidents are present. According to the research results, lane widths of 3.5–3.7 metres and paved or stabilised shoulders totalling up to about 10 m provide more lateral clearance and recovery area and thus, most likely benefit safety on rural two-lane main roads. There is indication that further pavement widenings possibly encourage to higher speeds and more careless driving which compensates the safety mar-
and thus, most likely benefit safety on rural two-lane main roads. There is indication that further pavement widenings possibly encourage to higher speeds and more careless driving which compensates the safety margin wide pavements provide and possibly, result an increase in accident costs even though the accident rate is reduced.

On other than main roads, where the standard of the road is poorer, the main focus is on single-vehicle accidents, but also on opposite direction accidents. Single-vehicle accidents are usually a result of too high operating speeds for the design of the road. Research results support the view that widening the lanes may not the right cure, but rather an increase in both the recovery and avoidance space, which could be achieved by stabilised shoulders and ‘forgiving roadside’ design.

To conclude, there is indication that treating geometric and roadside elements as clusters rather than individually would be a worthwhile approach for safety improvements on two-lane rural roads. Cleveland et al. (1985) concluded that road sections with the best and worst accident records have showed a strong influence of the bundles of geometric design factors on accident experience. For instance, even without considering the effect of ADT, geometric characteristics have shown a strong effect on off-road accident experience. Mountain (1995) has also reported significant safety effects of link improvements (e.g. realignment and widening).

In a recent European Road Safety Federation report (ERSF 1996) it has been stated that it is generally not possible to make any definitive statements concerning the level of safety of the road design on the basis of a consideration of individual elements of the road isolated from the overall interrelationship between the road elements, in particular, the alignment and the roadside treatment as with the cross-section.
Table 1. Research results of studies of cross section safety (lane width, shoulder type and width) on rural two-lane roads.

<table>
<thead>
<tr>
<th>Authors of the study</th>
<th>Year and country (state)</th>
<th>Object of the study</th>
<th>Effects on accidents (accident rates) (↑=accidents increase, ↓=accidents reduce)</th>
<th>Requirements or other notions</th>
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<td>Brannolte et al.</td>
<td>1992, Germany</td>
<td>×</td>
<td>↓</td>
<td>↓</td>
</tr>
<tr>
<td>Brannolte et al.</td>
<td>1993, Germany</td>
<td>×</td>
<td>↓</td>
<td>↓</td>
</tr>
<tr>
<td>Foody &amp; Long</td>
<td>1974, Ohio</td>
<td>×</td>
<td>↓</td>
<td>↓</td>
</tr>
<tr>
<td>Armour &amp; McLean</td>
<td>1983, Australia</td>
<td>×</td>
<td>×</td>
<td>↓</td>
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<tr>
<td>Rogness et al.</td>
<td>1981, Texas</td>
<td>×</td>
<td>×</td>
<td>↓</td>
</tr>
<tr>
<td>Rogness et al.¹</td>
<td>1982, Texas</td>
<td>×</td>
<td>×</td>
<td>↓</td>
</tr>
</tbody>
</table>
## Object of the study

Effects on accidents (accident rates)

\(\uparrow\) = accidents increase, \(\downarrow\) = accidents reduce

### Wider shoulder

- **Paved/stabilised**
- **Unpaved**

### All accidents

<table>
<thead>
<tr>
<th>Authors of the study</th>
<th>Year and country (state)</th>
<th>Wider lane</th>
<th>Wider shoulder</th>
<th>Effects on accidents (accident rates)</th>
<th>Requirements or other notions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(\uparrow)</td>
<td>All</td>
</tr>
<tr>
<td>Rogness et al.²</td>
<td>1982, Texas</td>
<td>×</td>
<td>×</td>
<td>(\downarrow)</td>
<td></td>
</tr>
<tr>
<td>Rogness et al.³</td>
<td>1982, Texas</td>
<td>×</td>
<td>×</td>
<td>(\downarrow)</td>
<td></td>
</tr>
<tr>
<td>Zegeer et al.¹</td>
<td>1987, 7 states in the USA</td>
<td>×¹</td>
<td>×²</td>
<td>(\downarrow)</td>
<td>¹0.3m→12% 0.6m→23% 0.9m→32% 1.2m→40% ²0.6m→16% 1.2m→29% 1.8m→40% 2.4m→49% ³0.6m→13% 1.2m→25% 1.8m→35% 2.4m→43%</td>
</tr>
<tr>
<td>Brüde &amp; Larsson</td>
<td>1994, Sweden</td>
<td>×</td>
<td>(×)</td>
<td>(\uparrow)</td>
<td></td>
</tr>
</tbody>
</table>

### Single-vehicle accidents

- All
- Run-off road
- Hit-fixed object

### Multi-vehicle accidents

- All
- Head-on
- Opposite direction (head-on or sideswipe)

**Note**: The table shows variations in shoulder width and lane width across different studies, indicating the impact on accident rates and severity. The studies varied in terms of traffic volume and accident severity, with some showing decreases in accidents and others showing increases.
## Object of the study

<table>
<thead>
<tr>
<th>Effect on accidents (accident rates)</th>
<th>Authors of the study</th>
<th>Year and country (state)</th>
<th>Object of the study</th>
<th>Requirements or other notions</th>
</tr>
</thead>
</table>
|                                     | Brüde & Larsson       | 1996, Sweden             | More extensive than the earlier study (above), the method used primarily was with-and-without study: existing roads with wide lanes were compared with remaining roads of the same type but without wide lanes (wide shoulders instead)  
→ accident rate, injury consequence and injury rate almost the same for both road types; same distribution for property damage and personal injury accidents, slightly injured, seriously injured and killed  
→ wide lanes had larger proportion of single-vehicle accidents but fewer rear-end, turning and crossroad accidents (also see Brannolte et al. 1993) | *+1 m carriageway width |
|                                     | Hughes & Amis         | 1996, Great Britain     | ↓ 19%*              | Roads with 0.9m and 1.2m paved shoulders lower acc. experience and severity index compared to similar unpaved. |
|                                     | Heimbach et al.       | 1974, North Carolina    | × × ▼              | Accident cost rate increased with increasing carriageway width. |
|                                     | Hiersche et al.       | 1984, Germany           | × × ▼              | Accident cost rate increased with increasing carriageway width. No significant independent effects of pavement or shoulder width in the total accident prediction. |
|                                     | Cleveland et al.      | 1984, Michigan          | × × —              | No significant independent effects of pavement or shoulder width in the total accident prediction. |
|                                     | Brüde et al.          | 1980, Sweden            | Study compared accidents for roads of different pavement widths:  
→ for 90 km/h speed limit accident rate decreased with increased paved width, injury consequences worst on paved widths ≥ 12.75 m  
→ for 70 km/h speed limit accident rate lower when paved width ≥ 11.3 m  
→ for 110 km/h speed limit accident rate and injury consequences highest on paved width of 11.3–12.8 m | |
|                                     | Larsson               | 1977, Sweden            | Study compared accident rates for 90 km/h roads of different pavement widths:  
→ accident rate decreased with paved width up to 10 m | |
|                                     | Brüde & Nilsson       | 1976, Sweden            | Study compared accident rates for 90 km/h roads of different pavement widths:  
→ accident rate decreased with paved width up to 10 m | |
|                                     | Roine & Kulmala       | 1991, Finland           | Widening the pavement may reduce the accident risk, but hilliness of the road and traffic volume also contribute to the outcome. Wider lanes possibly do not give favourable safety effects on hilly roads and low traffic volumes. |
### Object of the study

Effects on accidents (accident rates)

\[ \uparrow = \text{accidents increase}, \downarrow = \text{accidents reduce} \]

<table>
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<th>Authors of the study</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Wider lane</td>
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<td></td>
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<td>Wider shoulder</td>
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<td></td>
<td></td>
<td>Paved/ stabilised</td>
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<td>Un-paved</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>All accidents</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Personal injury acc.</td>
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<td></td>
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<td>Single-vehicle accidents</td>
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<td>All</td>
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<td></td>
<td>Run-off-road</td>
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<td></td>
<td>Hit-fixed object</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Multi-vehicle accidents</td>
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<td></td>
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<td>All</td>
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<td>Head-on</td>
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<td></td>
<td></td>
<td></td>
<td>Opposite direction</td>
<td>head-on or sideswipe</td>
</tr>
<tr>
<td>Peltola</td>
<td>1995, Finland</td>
<td>On main roads, the risks for personal injury and death reduced with wider pavements. On other than main roads, the risk of death increased with wider pavements especially with lower traffic volumes (greater risk for single-vehicle, passing and head-on accidents).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Edholm &amp; Roosmark</td>
<td>1969, Sweden</td>
<td>Accident frequency was higher for carriageway width of 6–6.5 m compared to 7–8.5 m. Roads were selected so to have similar characteristics to control for other factors. Paved shoulders were beneficial for safety.</td>
<td></td>
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</tr>
<tr>
<td>Johansson</td>
<td>1985</td>
<td>Accident rates were about the same for 6–8.5 m (ADT 1500) and 10–13 m (ADT 4000) roads with a speed limit of 90 km/h. The roads were originally selected in order to compare roads that are built in 1950’s, 60’ and 70’s.</td>
<td></td>
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</tr>
<tr>
<td>Ogden</td>
<td>1995, Australia</td>
<td>×</td>
<td>↓</td>
<td>Adding 0.6 or 0.8 m paved shoulders to a 7.4 m wide road. Reduction was found also in rear-end and overtaking acc.</td>
</tr>
<tr>
<td>Vejdirektoratet</td>
<td>1980, Denmark</td>
<td>Accident rate was lower on 7–8 m wide carriageway compared to 6–7 m.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vejdirektoratet</td>
<td>1984, Denmark</td>
<td>×</td>
<td>↓</td>
<td>Paved shoulder increase 0.2→0.5 m: vehicle accidents – 25%, pedestrian and cyclist acc. – 40%.</td>
</tr>
</tbody>
</table>
REFERENCES


Johansson, Ö. 1985. Traffic safety on roads projected/built in the fifties, sixties and seventies. Swedish National Road Administration, Technical Department, Section for Development. TU 1985:5.


