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Evaluation of 2+1-roads with cable barrier

Final report

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Evaluation of 2+1 roads with cable barrier. Final report

Abstract (background, aim, method, result) max 200 words:

The Swedish Road Administration started in 1998 a development program denoted alternative 13 metre roads, since 2002 denoted ”collision-free roads”. The program objectives were to increase the traffic safety on existing 13 m-roads and semimotorways (two-lane expressways) in an cost-effective manner with significantly lower investment costs and smaller intrusion compared to traditional measures. These actual roads with a total length of about 3,700 km during the 1990s, of which 350 km were semimotor-ways, comprised about 25 % of the mileage on the main road network but only 14 % of the length. During the 1990s there were almost 100 yearly fatalities and 400 severe injuries on this network, which corresponded to almost 25 % and 20 % respectivly of the total numbers on the national road network.

To ensure that the objectives should be achieved a comprehensive evaluation and follow-up was started of all the measures undertaken in the scope of the development program. This evaluation should ensure that important impact factors for costs and effects were considered.

This publication is a summarized final report and documentation of results and experiences from the extension of collision-free roads, from the beginning 1998 to 2006–2007, when the evaluation gradually has been finished.

Keywords:
Collision free road, 2+1-road with cable barrier, effects on traffic safety, travel speeds, maintenance costs

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Inom Vägverket startades 1998 ett utvecklingsprogram benämnt alternativa 13 m-vägar, senare benämnt mötesfria vägar. Syftet med detta program var att på ett kostnadseffektivt sätt öka trafiksäkerheten på då befintliga 13 m-vägar och motortrafikleder (ML) med väsentligt lägre investeringskostnader och mindre intrång än vid traditionella åtgärder. Dessa vägar, med en total längd på ca 3 700 km under 1990-talet varav 350 km ML, omfattade ca 25 % av trafikarbetet på huvudvägnätet men endast 14 % av längden. Under 1990-talet omkom på dessa vägar årligen nästan 100 trafikanter och skadades svårt nästan 400, vilket motsvarade nästan 25 respektive 20 % av totalantalet på statliga vägar.

För att säkerställa att syftet enligt ovan blev uppnått inleddes en omfattande uppföljning och utvärdering av de åtgärder som vidtogs inom ramen för utvecklingsprojektet. Denna utvärdering skulle säkerställa att man inom ramen för utvecklingsprogrammet beaktade viktiga faktorer beträffande kostnad och effekter.

Denna publikation utgör en sammanfattande slutrapport och dokumentation på engelska av resultat och erfarenheter från utbyggnaden av mötesfria vägar från starten 1998 till och med 2006–2007, då uppföljningen av mötesfria vägar successivt har avvecklats.

Nyckelord:

Mötesfri väg, 2+1-väg med mitträcke, trafiksäkerhetseffekter, framkomlighet, DoU-kostnad

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Foreword

The Swedish Road Administration (SRA) started in 1998 a development program concerning alternative 13 m roads. The program objectives are to improve the traffic safety standard on existing 13 m roads and semi-motorways (SMW) in a cost-effective manner with significantly lower investment costs and less intrusion compared to traditional methods.

To ensure that the objectives should be achieved a comprehensive evaluation and follow-up has been performed of all the measures undertaken in the scope of the development program. This evaluation should ensure that important impact factors for costs and effects were considered.

This publication is a summarized final report and documentation of results and experiences from the evaluation of the program for collision-free roads. The evaluation has been performed at VTI on commission of the SRA.

Arne Carlsson has been the project leader for the evaluation at VTI. Ulf Brüde at VTI has been responsible for the collection and compilation of accident data and outcome.

The Office for Road Design at SRA has financed the evaluation. Torsten Bergh has been the purchaser and partner at SRA the first five years of the evaluation, then followed by Jan Moberg.

Linköping January 2009

Arne Carlsson
Project leader

Cover: Vägverket, Region Mitt

Quality review

Review seminar was carried out on 9 September 2008 where researcher Mats Wiklund reviewed and commented on the report. Arne Carlsson has made alterations to the final manuscript of the report. The research director of the project manager, Maud Göthe-Lundgren, examined and approved the report for publication on 18 December 2008.

Kvalitetsgranskning

Granskningsseminarium genomfört 2008-09-09 där forskare Mats Wiklund var lektör. Arne Carlsson har genomfört justeringar av slutligt rapportmanus hösten 2008. Projektledarens närmaste chef, Maud Göthe-Lundgren, har därefter granskat och godkänt publikationen för publicering 2008-12-18.

Contents

Evaluation of 2+1 roads with cable barrier

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Summary

This is in summary the final report on the program by the Swedish Road Administration (SRA) to develop alternative 13 metre roads, since 2002 denoted ”Follow-up of Collision-free[1] Roads”. The program objectivs are, inter alia, to clarify consequences for level-of-service and traffic safety. The report gives an overview of all important facts and effects for 2+1 roads with cable barriers.

As of January 1, 2008 about 1,800 km of collision-free roads have been opened for traffic. In addition there are about 120 km of so called “alternative four-lane road” (Alt 4L), newly built road segments with a width of 18.5 m and 2.5 m wide median.

Effects on traffic safety

Casualty data have been monitored for the number of killed and for fatality rate (F-rate) for the total rebuilt road network. The following summarised results show the effect on collision-free roads compared with old-type 13 m roads and expressways (SMW).

- The total number of killed are 54 for the 2+1 road objects. This corresponds to an F-rate of 0.0026. If only the links are included (i.e. excluding fatal crashes in intersections between state roads) the number of killed is 43, which gives 0.0021 as the F-rate for links.
- Compared to the normal outcome for 13 m roads or SMW without reconstruction the reduction in fatalities is 76%. For road links the reduction is 79%.
- The observed F-rate for 2+1 links – 0.0021 – is exactly the same as “normal” outcome for motorways with 110 km/h.

Travel speeds

- Level-of-service for 2+1-roads is better than expected. The average travel speed for cars has increased somewhat 2 km/h for 90 km/h and is the same for 110 km/h.
- The capacity is about a directional flow of 1,600–1,650 veh/h during a 15 minutes period. This capacity value is about 300 veh/h lower than for an ordinary 13 m-road. The bottleneck is always the transition 2 to 1 lane.

Maintenance costs; added costs compared with 13 m

- The total added costs on 2+1-road for the SRA as road authority are 85,000–95,000 SEK per km and year at the highest. If increased standard level is used the costs are maximum 100,000–110,000 SEK per km and year.

[1] Also called ”meeting-free roads” since the objective is to design and build roads that prevents head-on collisions.

Uppföljning av mötesfria vägar. Slutrapport

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Sammanfattning

Detta är slutrapporten för Vägverkets utvecklingsprogram alternativa 13 m-vägar, sedan 2002 benämnt ”Uppföljning mötesfria vägar”. Syftet med programmet är bland annat att klarlägga framkomlighets-, trafiksäkerhets- och miljöeffekter. Denna rapport är en engelsk sammanfattning av slutrapporten som ger en översikt av alla väsentliga faktorer och effekter för mötesfria vägar.

Räknat per 1 januari 2008 har ca **1 800 km** med mötesfri väg öppnats för trafik. Dessutom finns cirka 120 km med så kallad alternativ fyrfältsväg (Alt 4F), nybyggd väg med bredden 18,5 m och mittremsa 2,5 m.

Trafiksäkerhetseffekter

Antal dödade och dödskvot har följts upp på det totalt ombyggda nätet, redovisat ovan till och med år 2007. Följande sammanfattande resultat visar effekten på mötesfria vägar jämfört med 13 m-väg och ML, motortrafikled.

- Totalt antal dödade på 2+1-objekten är 54 vilket motsvarar en dödskvot på 0,0026. Räknat på enbart väglänk (exklusive dödsolyckor i korsningar statliga vägar) är antalet 43, vilket ger kvoten 0,0021
- Jämfört med normalt utfall på 13 m eller ML innebär observerade dödstal en **reduktion med 76 %.** Räknat enbart för länk blir det en **reduktion på 79 %**
- Observerad dödskvot för länk på 0,0021 är exakt samma som normalt utfall på motorväg med 110 km/h.

Tillgänglighet och reshastighet

- Trafikavveckling och framkomligheten är bättre än förväntat
- Medelhastigheten för personbil har ökat med cirka 2 km/h på 90 km/h och är oförändrad vid 110 km/h
- Enbart små fördröjningar för personbil i enfältiga avsnitt upp till cirka 1 000–1 200 f/h per riktning
- Kapaciteten ligger på ca 1 600–1 650 f/h i en riktning för en 15 minutersperiod. Detta värde är dock cirka 300 f/h lägre än för ML/13 m. Det är alltid övergången 2 till 1 körfält som utgör flaskhalsen.

Drift- och underhållskostnader, DoU, merkostnad jämfört med 13 m

- Totalt för all DoU på 2+1-väg erhålles en ökad väghållarkostnad på **max 85–95 tkr per km och år.** Vid ökade standardkrav ökar beloppet till max 100–110 tkr.

0 Explanations to concepts and abbreviations

Accident rate AR	Accidents (crashes) reported by the Police (including property damage only) per million axlepair kilometres.
Injury accident IA	Police-reported crash (accident) with casualty/ies (injured or killed) as consequence.
Injury accident rate; IA-rate	Number of injury accidents (fatal accidents included) per million axlepair kilometres.
Injury rate I-rate	Number of injured or killed per million axlepair kilometres.
FSI-rate	Number of seriously injured (incl. killed) per million axlepair kilometres
Fatality rate F-rate	Number of killed per vehicle mileage. Vehicle mileage is usually expressed in million axle pair kilometres (apkm)
Injury ratio	Number of injured (killed included) per accident/crash reported by the Police or per injury accident/crash, depending upon type of crash.
Serious injury ratio, SC	Number of seriously injured (killed included) per accident/crash reported by the Police or per injury accident/crash, depending upon type of crash.
Guardrail collision rate; G-rate	Number of median guardrail crashes on collision-free roads per million axlepair kilometres. Only 20-25% of the guardrail collisions become reported by the Police. Injuries are unusual, but vehicle damages can be extensive.
13 m road	A “traditional” type of two-lane road in Sweden – two 3.5 m wide lanes and 3 m wide paved shoulders
Alt 4L	“alternative four-lane road”, narrow 4-lane roads with a width of 18.5 m and 2.5 m wide median
MW	Motorway with minimum two lanes in each direction (2+2), broad shoulder and a median and interchanges.
SMW	“Expressway”, dual carriageway roads, usually 13 m wide with interchanges. Slow-moving vehicles, bicyclists, pedestrians etc. are not allowed to use MW and SMW-roads.
MLV	Collision-free road, generally comprising 2+1 lanes and median with a barrier (often wire guardrail). The width is 13 to 14 metres. MLVs have at-grade intersections with an opening in the median barrier. The cross section at large intersections is usually 1+1 through lanes and with a lane for left-turn traffic. There are also designs with a roundabout.
MLV(2+2)	Collision-free road or expressway with 2+2 lanes and median with barrier. The width is 15.5 – 16.5 m. MLV(2+2) roads have at-grade intersections, with an opening in the barrier, with 1+1 through lanes and in larger intersections left-turn lanes. Alternatively an intersection can be a roundabout.

MML	Collision-free expressway usually with 2+1 lanes and median with a barrier (often wire guardrail). The width is 13 to 14 metres. MML has interchanges with exit- and entry lanes. Slow-moving traffic, cyclists etc. are not allowed.
Road link	Segment of the actual road between two intersections with state roads. A road link normally contents connections with private roads and/or exits from properties
Node	Intersection between state roads

1 Background

This is the final report on the follow-up of the program by the Swedish Road Administration (SRA) to develop alternative 13 metre roads, since 2002 denoted ”Follow-up of Collision-free[2] Roads”. The program objectivs are, inter alia, to detect and clarify standards and cost levels for suggested measures and to clarify consequences for level-of-service, traffic safety and the environment.

Initially the program covered six road segments with separation by cable barrier in the median, one for each SRA region except the Stockholm region. During spring 2000 the SRA decided to rebuild rapidly a large number of high-class 13 metre roads, of which most were ”expressways[3]” (SMW), to 2+1 roads with cable barrier in the median. A large number of road segments were opened in 2001–2004, in most cases rebuilt ordinary 13 metre roads but also ”expressways” (smw). In addition, the evaluation includes eight 2+1 road segments with only road markings and six road segments of the type called “alternative four-lane road”.

As of January 1, 2008 about 1,800 kms of collision-free roads have been opened for traffic. In addition there are about 120 kms of so called “alternative four-lane road” (Alt 4L), newly built road segments with a width of 18.5 m and 2.5 m wide median. The distribution on road types is as follows:

- about 470 kms of collision-free expressways (MML), of which 366 kms have 110 km/h speed limit;
- about 1,275 kms of collision free highways (MLV), of which 400 kms have 100 km/h speed limit;
- about 50 kms of collision free roads with 2+2 design with 16 m road width and 90 km/h;
- about 120 kms of alternative four-lane road, of which 100 kms have 110 km/h speed limit.

The majority of all rebuilt objects has been financed by special designated funds for traffic safety on the national trunk roads. Very few objects are build with funds from the ordinary national investment plan.

[2] Also called ”meeting-free roads” since the objective is to design and build roads that prevents head-on collisions.
[3] See explanations of abbreviations and concepts in chapter 0 in the beginning.

2 Effects on traffic safety

Casualty data have been monitored for the number of fatalities and for fatality rate (F-rate) for the total rebuilt road network. The following summarised results show the effect on collision-free roads compared with old-type 13 m roads and expressways (SMW).

- The total number of killed are 54 for the 2+1 road objects. This corresponds to an F-rate of 0.0026. If only the links are included (i.e. excluding fatal crashes in intersections between state roads) the number of killed is 43, which gives 0.0021 as the F-rate for links.
- The normal outcome for 13 m roads or SMW without reconstruction would have been 228 killed. The reduction is thus 76%. The corresponding outcome for links would have been 208, which corresponds to 79% reduction.
- The MLV-objects have an observed outcome twice as large as for MML (expressways) on links, 0.0028 compared 0.0014, despite a significant lower traffic mileage at posted speed 110 km/h.
- The observed F-rate for 2+1 links – 0.0021 – is exactly the same as "normal" outcome for motorways with 110 km/h.
- 2+1 road objects with 110 km/h have a link F-rate of 0.0027, a 76% reduction, and objects with 90 km/h have an F-rate of 0.0017, an 82% reduction.
- MLV(2+2) roads with 90 km/h have an F-rate of 0.0023 both overall and for links only. This is more or less the same outcome as that of all 2+1 objects and it is a 75% reduction.
- Narrow four-lane roads (Alt 4L) with 110 km/h have an overall F-rate of 0.0040 and 0.0034 for links, i.e. higher values than for 2+1 with 110 km/h. Four driving lanes has no observed traffic safety effect.

The outcome as accident rate, injury rate and FSI-rate has been monitored for a smaller road network comprising 1,200 kms of 2+1 roads, 30 kms of 2+2 roads and about 75 kms of Alt 4L roads. This monitoring and follow-up also includes 2+1 roads with road markings only. Besides the rates mentioned analyses have also been made of injury and severity ratios. The following results for accident rate and injury rate are notable.

- The MML road objects and Alt 4L generally show unchanged or marginally lower injury accident rate (IA-rate). The injury consequences are 8-13% lower, which results in a 10-15% lower injury rate.
- MLV roads with 90 km/h have a 20% lower IA-rate, while MLVs with 110 km/h have a IA-rate that is about 20% higher. The injury consequences are almost unchanged, so the injury rate has decreased/increased by about 20% respectively.

The negative outcome in IA-rate for MLV-110 might be explained by a geometric standard (alignment and roadside area) that on average is lower than that of 13 m roads with 110 km/h.

The changes in FSI-rate are of great interest. Table 1 shows FSI-rates for the different road types and speed limits. The table also shows the actual reduction in FSI outcome compared with that of normal road types and different speed limits. Finally, table 1 shows serious injury ratio (SC) for links, which here is the number of **FSI per injury accident.**

Table 1 The outcome as FSI-rate, total and for links, and SC for collision-free roads per Dec. 2006 or Dec. 2007. Comparison with normal rate or ratio for expressways and 13 m roads.

Type and speed limit	FSI-rate		Reduction (%)		SC links	Reduction (%) links
	Links plus junctions	links	Links plus junctions	links		
MML 110	0.0219	0.0209	57	56	0.25	58
MML 90	0.0177	0.0146	62	66	0.19	63
MLV 110	0.0305	0.0238	39	46	0.25	55
MLV 90	0.0177	0.0104	63	74	0.17	66
MLV(2+2) 90	0.0195	0.0177	59	70	0.20	58
Alt 4L 110	0.0218	0.0204	57	58	0.25	58
2+1,painted 90	0.0323	0.0250	31	39	0.31	36

In summary, the reduction in FSI-rate for MML 110 and Alt-4L 110 is **56–58%**, which is explained completely by the **corresponding reduction in serious injury ratio.** MLV 110 shows the same serious injury ratio but these roads have a lower reduction in FSI on links, **about 45%**, which is the effect of a **higher injury accident rate.**

MLV with 90 km/h has the largest reduction for links – **more than 70%** – which is due to about 65% lower serious injury ratio and a 25% lower PO-rate. However, for these roads must be added **a 70% addition for nodes (junctions)**, which gives a total reduction more than 60%. This means that the total FSI-rate, including junctions, is the same as that of MML and MLV with 90 km/h.

The majority of accidents on collision free roads are run off- and rear end-accidents, which together correspond to 60–80 % of all FSI-accidents. For other types of accident it can be mentioned that the observed FSI-rate for vulnerable road-users on MLV has been reduced with about 90 % (vulnerable users are not allowed on MML).

The outcome as FSI-rate for **painted 2+1 roads** is overall about 80% higher and for links 100% higher (doubled) compared with an average of MML 90 and MLV 90. However, in comparison with ordinary SMW/13 m roads there is almost a 40% reduction in FSI for links. The explanation is that the serious injury ratio has been reduced by 35%. (The remaining effect is due to a 5% lower IA-rate).

The conclusions above are somewhat uncertain since vehicle mileage is low for painted 2+1 roads. However, there are indications that painted 2+1 roads with median rumble strips has a 35-40% reduction of number of seriously injured or killed compared with SMW and 13 m roads. Almost all of this effect can be explained by lower serious injury ratio.

Road safety outcome for motorcyclists

During almost the whole development program there has been a discussion on whether the 2+1 design with a cable barrier increases the risk of injury or death for motor-cyclists. An analysis has been made in which the outcome for motorcyclists, as killed (all objects) and FSI (monitored network), has been compared with the outcome for all accidents in the country in relation to the total accident outcome nationwide.

The FSI outcome for motorcyclists (MC) on the monitored network of 1,170 kms is as follows:

- On 2+1 roads a total number of 6 fatalities and 17 seriously injured, of which 1 fatality and 3 seriously injured in nodes/junctions.

The MC outcome of 23 FSI on 2+1 roads corresponds to a **proportion of 7.8%**. This is slightly lower than the nationwide proportion of 9.3%.

9 MC users have been killed on the total network of collision-free roads, one of which on MLV 2+2. Four of nine fatal crashes involved the cable guardrail and three occurred in nodes (junction or interchange).

The outcome – 9 fatalities – corresponds to a **proportion of 16.1%** (9 of 56). This is a higher proportion than that of the whole country (11.5%). However, overall there is a 75% reduction in fatalities on the collision-free roads. This must mean that there is **a substantial reduction also in the number of killed motorcyclists** (and also a reduction in FSI for this category).

An analysis has been made in which the number of fatalities or seriously injured motorcyclists is predicted for 13 m roads and expressways (SMW) without redesign. The motorcycle mileage has then been assumed to be 0.95% of the total mileage. This corresponds to the national MC mileage. This analysis indicates that the number of killed or seriously injured **has been reduced by 65–70%** by rebuilding to 2+1 type of road.

Among the possible objections are that the risks to motorcyclists on 13 m roads and SMW ought to be lower that the nationwide average and that the mileage proportion is less than 0.95%. A sensitivity analysis in which predicted outcome is halved shows that in comparison with the general outcome there is a **reduction of 32–35%** in the number of killed or seriously injured motorcyclists.

With the above analysis as a basis it can be stated that **there is no evidence that the FSI or fatality risks for motorcyclists have increased on collision-free roads** compared with SMW or 13 m roads. On the contrary, it can be stated that FSI and fatality risks for motorcyclists have been reduced by 40-50% on 2+1 roads with cable median guardrail.

Collisions with Guardrails

The follow-up of collision with median guardrails includes most of the road objects monitored for accident development (see above). In addition there has been a follow-up of collisions with guardrails on Alt 4L objects until and including 2006.

The follow-up of cable barrier collisions on MML objects shows that until December 2006 the collisions rate was **0.50 per million axle pair kms** (apkm). This rate is generally lower for MLV objects. The collision rate for 30 road objects is **0.43 per million apkm**. The difference can be explained by on average lower annual average daily traffic (AADT) for MLV objects and a higher proportion of MML objects with 110 km/h. The objects in the north (the two SRA[4] regions VM and VN), both MML and

[4] SRA = Swedish Road Administration

MLV, have an average rate of **0.59** collisions per million apkm while road objects in other SRA regions have an average value of **0.43.** There is thus a pronounced difference between the two northern SRA regions and the other ones.

The four objects with 4L design and 110 km/h have an average guardrail collision rate of **0.28** per million apkm, i.e. substantially lower than for the MML objects. The rate is of the same magnitude as that of MML and MLV objects with the lowest rate. The three objects with 2+2 design and 90 km/h have a guardrail collision rate of **0.37** per million apkm. This rate is higher than that of 4L objects and about 15% lower than the average for MLV objects.

A tentative analysis has been made for the 2+1 objects of the influence of different factors. Data were grouped as MML and MLV objects in SRA regions VN+VM (north) and remaining regions (south) with simultaneous grouping in speed limits 90 and 110 km/h. Regression analysis has also been used in the analysis.

The overall results indicate that northern Sweden, 110 km/h and higher AADT raises the guardrail collision rate while wider centre median strip lowers it. It has not been possible to show distinct differences between MML and MLV. For the time being, it can be assumed that the following is true for a multiplicative explanatory model:

The estimated guardrail collision rate for MLV objects in southern Sweden with 90 km/h, median width < 1.75 m (and AADT < 9,000)	**0.35**
Multiplicative factor for MML	**1.00**
Multiplicative factor for northern Sweden	**1.20–1.30**
Multiplicative factor for 110 km/h	**1.20–1.25**
Multiplicative factor for median width < 1.75 m	**0.80–1.00**
Multiplicative factor for AADT ≥ 9,000	**1.25–1.35**

The conclusions from the regression analysis can be summarised as follows:

- SRA regions VN+VM (in the north) have 25% higher guardrail collision rate than regions in the south.
- The 110 km/ speed limit has 15–25% higher rate than 90 km/h.
- 14 m road width has only effect in southern Sweden and mainly for MML objects. However, with a median of 1.75 m or wider it is possible to obtain an overall reduction of 20%.
- Road objects with AADT greater than 9,000 has 25–30% higher rate.
- A sub-division into smaller segments shows that the guardrail collision rate is considerably higher for one-lane segments compared to two-lane segments. For the MML objects, which on average have a guardrail collision rate of 0.50, the rate is 0.70 for one-lane segments and 0.33 for two-lane segments. The later value is lower than that of the two 2+2 objects but higher than for objects with 4L design.

3 Travel speeds

The effekt of 2+1 design on speed and level-of-service has foremost been analysed for two MML objects, E4 between Gävle and Axmartavlan and E18 between Västjädra and Västerås. The basis for the analyses was a large number of measurements, spot speed measurements and floating car (FC) measurements when traffic flows were high.

In addition, spot speeds were measured for two painted objects, the northern part of E4-Gävle (before the segment with median cable barrier) and E22-Karlshamn, and also on some MLV-objects. The results are summarised below.

- Travel speeds for passenger cars (pc) at 90 km/h speed limit have increased somewhat, 2 km/h with median barrier and 4 km/h with painted design, Measurements on E22-Karlshamn show a 1 km/h increase in travel speed compared with ordinary SMW.
- At the 110 km/h speed limit, passenger cars travel at an average speed level of 108.5 km/h with a 5 km/h speed difference between one- and two-lane segments.
- These results are for flows up to about 500 vehicles/hour and direction. At higher flows there is a small decrease in speed level for one-lane segments.
- The speed level for passenger cars in the left lane on two-lane segments is on average about 120 km/h.
- There is substantial longitudinal speed variation between one- and two-lane segments when flows are above 900 vehicles per hour per direction.
- However, the speed reduction at high flows is lower than expected for one-lane segments.
- One can expect capacity breakdown, rather sudden, at a directional flow of 1,600–1,700 v/h during a 15 minute period. This corresponds to a one-hour flow of 1,500–1,550 and this capacity value is about 300 v/h lower than for an ordinary SMW.

4 Operating costs; added costs compared with 13m roads

A number of studies of operating costs for 2+1 roads have been carried out within the framework of the follow-up of three different road objects. Follow-up of additional objects also exists. The operating costs per km road and year before and after rebuilding have been calculated. Corresponding costs for a control segment close to each object have also been calculated. The added costs for 2+1 or 2+2 designs have been calculated as the difference between after and before**, but in relation to the corresponding difference for the control segment.**

In summary the results were as follows:

The costs for **winter road maintenance** have increased with **SEK 2–10,000 per km and year**. However, costs for three MML object in VSÖ[5] were considerably higher – SEK 15-30,000 per km per year. This increase is largely due to changed functional requirements with need for additional resources. **Salt use has not increased** for road widths of 13-14 m. Salt use remains unchanged at about **0.1 tons per km** per occasion with slipperiness or snow. For the whole winter this means 10–20 tons per km, depending upon climate zone.

The pre-study assumed a **total added cost, exclusive of the median cable barrier**, of about SEK 80,000 per km per year of which 30–35,000 for winter road maintenance. The actual outcome was substantially lower. The calculations indicate that the costs to SRA as road authority are **SEK 5–20,000 per km** of which winter road maintenance is SEK 2–10,000 as mentioned above. The major part of other added costs is for road equipment – about SEK 3,000 per km per year and for maintenance of the roadside area.

The costs for the centre guardrail account for the largest increase. Collisions with guardrails are in the interval of 0.4–0.7 per million axle pair kilometres, depending upon location and winter climate. The guardrail repair cost is about SEK 13,000 per occasion.

The guardrail collision rate for MLV objects, with the average AADT of 7,900 vehicles, is 0.43 per million axel pair kilometres (apkm) which gives 1.24 guardrail hits per km per year. This results in a cost of **SEK 16,000 per km per year**. The corresponding data for MML objects are 0.50 per million apkm and AADT 10,200. This gives a cost of **SEK 24,000 per km per year**.

However, the net cost for SRA (the cost to SRA as road authority) is only 10% of the above or about SEK 1,300 on average for each instance of guardrail repair. This implies an **added cost for guardrail repair of about SEK 2,000 per km per year**. The remaining 90% of the repair costs is a pure **accident cost** which is paid by car drivers /owners and insurance companies. This cost amounts to 14–22,000 per km per year, depending upon guardrail collision rate and AADT. Some SRA regions also include a **write-off cost of SEK 10,000 per km per year** covering replacement of the median guardrail.

[5] VSÖ = SRA, region south-east

Accident costs for repair of vehicles should be added to the above. The repair costs after colliding with a cable barrier can be estimated to be about SEK 40,000. With 1.3–1.9 guardrail collisions per km per year this means **an accident cost of 50–75,000 per km per year**. Car owners and insurance companies pay these costs. The insurance costs for cable barrier repairs can be counted as accident costs (see above), which means added guardrail repair costs of SEK 14–22,000 per km per year, making a total of SEK 65-95,000 per km per year, the lower value for MLV and the higher for MML.

5 Pavement Maintenance

In the SRA pre-study there was an analysis of differences in rut depth growth and resulting pavement costs in the PMS model then used by SRA. That model is based on measurements of **road conditions from 1987 until the beginning of the 1990's**. This model predicts an annual rut depth growth of **1.6 mm for a 9m road and 1.3 mm for a 13m road** with normal lane widths and an **AADT of 10,000 axle pairs**. As a template it is assumed that around 1990 rut depth growth was to **80% caused by wear** from vehicles with studded tyres and **20% was deformation** caused by heavy vehicles.

Additional ruth depth measurements have been made on primary state roads all over Sweden **after 2000**. The results show a rut depth growth which only is half that of the PMS model, i.e. 0.8 mm for 9m roads and 0.6 mm for 13m roads. The explanation to this substantially smaller rut depth growth is assumed to be that the cause is **less wear – only 20% – and more deformation – 80%.**

VTI has measured rut depths on four different collision-free road objects, including one with 2+2 design. The measurements have been analysed for each road segment and lane (one-lane segments, right and left lane for two-lane segments). In addition there are results from annual measurements commissioned by the SRA. These measurements give average results for one-lane segments and right lane parts of two-lane segments.

The positive development for 13m roads – halving of the rut depth growth – cannot be found for 2+1 roads. Rut wear is of the same magnitude as in the PMS model from the beginning of the 90-ies. This means a rut depth growth for one-lane segments that is the **same as for the 9-13m roads of the 90-ies**. Rut wear on two-lane segments is comparable to motorways (MW), but the left lane is generally better (less wear) than MW left lanes.

The conclusion of the above is that pavement maintenance costs for 2+1 roads with average or good road construction ought to be similar (relatively) to that of a 9m or 13m road in the beginning of the 1990-ies. For a 2+1 road with AADT 10,000 axle pairs this means a cost of SEK 45-54,000 per km per year in the price level of 1992. This can be compared with an ordinary 13m road for which the cost was SEK 45,000 per km per year at AADT 10,000 axle pairs.

However, there are probably also cost increases due to more extensive road marking arrangements during pavement works and less efficient work methods than for an ordinary two-lane road. A rough estimate of this cost increase is about SEK 2 per sq. m. and year at the 2005 price level. This means that if 11.5 m of the road width becomes resurfaced (no resurfacing of the median strip) the **extra cost becomes SEK 23,000 per km per year** at the 2005 price level. However, the extra cost becomes very small if traffic is diverted to alternative routes during resurfacing.

However, rut depth measurements show that after 1997 there has been a **reduction in rut depth wear by 50%** or more on ordinary 13m roads. The reduction for 9m roads is about **40% and that of MW 50–60%.** The reason is that wear of vehicles with studded tyres now only cause about 20% of rut depth growth while 80% is deformation caused by heavy vehicles. This positive development cannot be seen on 2+1 roads. More traffic "bound" to the ruts appears to cause faster growth of rut depth, of which 50% is wear and 50% deformation. This means a pronounced difference in rut depth growth between 2+1 roads and ordinary two-lane roads or motorways. However, it must be remarked that it is reasonable to assume that a likely positive development would have occurred also for 2+1 roads had they been in use already by 1990 and thus possible to monitor.

Anyway, it seems obvious that 2+1 roads have higher costs for pavement maintenance when the comparison is made with the **lower level for ordinary roads**, which should be valid after 2000. A rough estimate is that this extra cost due to more rut depth wear is SEK 3 per sq. m. per year at the 2005 price level. The assumption is then that there is a period of 12 years between resurfacings. This might be somewhat low. The resurfacing span for good road constructions should be about 14 years at AADT 10,000 axle pairs.

As a consequence the extra cost due to more rut dept wear ought to be in the interval of SEK 2.60 to 3.00 per sq. m. per year (price level of 2005). This corresponds to **SEK 30–35,000 per km per year**. Together with the extra costs for traffic arrangements (see above) this means total extra costs amounting to **SEK 53–58,000 per km per year** for average or good road constructions. Please note that this is valid for **the lower cost level from 2000 and onwards**.

Summary of added costs for service and maintenance

The added costs for service measures (see above) can now be added to the costs for pavement maintenance. The following table is obtained which shows added costs for service measures and maintenance:

Type of measure	**SEK*1,000 per km per year**
Winter road maintenance	**maximum 10, 20–30 if increased standard level**
Other fixed and mobile measures	**maximum 15**
Pavement maintenance	**50–60, 30–35 if traffic diversion to other route**
Guardrail repairs	**about 12, including write-off cost of 10** **net cost for SRA**
Total road authority cost	**maximum 85–95,** **100–110 if increased standard levels**
Accident cost, guardrail collision	**65–95 (car rep. 50–75, guardrail rep. 15–20)**

6 Transport Quality and vulnerability (risks)

Fear was expressed in the pre-study that there might be many jams and stops in traffic due to accidents and vehicle breakdowns on one-lane segments. It has been difficult to monitor this since there is no regular follow-up or compilations of vehicle breakdowns. However, in general these problems have been smaller than anticipated and only shorter stops have occurred.

A pilot study was carried out at RIT[6] which included analyses of speed data for one year and two MML objects. These data were combined with collection of data on traffic disturbances and weather. A study was made of the number of hours with mean speed less than 80 km/h for different types of disturbances.

It has only been possible to identify a few occasions of speed decreases caused by physical obstacles. The number of hours with speeds lower than 80 km/h **caused by incidents or physical obstacles is less than 0.05%** of all hours on the two road segments. During these few observed occasions (hours) the average speed has been about 65 km/h for both segments.

The other instances of speed decreases are almost completely due to snowy weather and snow ploughing or high traffic flows with more than 1,000 vehicles/hour in one direction. The latter only occurred for one of the segments – E18 Västjädra-Västerås – with an AADT of about 20,000 vehicles.

One additional study of "vulnerability" has been made. Transek, a traffic planning Consultant Company, carried out a "vulnerability analysis" as a quantitative comparison of data on stops, re-routing, accidents etc. The study comprised four types of collision-free roads:

1. 2+1 road (MML or MLV), for different road segments;
2. Motorway with 21.5 m road width, one road segment;
3. Alternative 4-lane road with 18.5 m road width, for road segments;
4. MLV 2+2 with width 16m, two road segments.

Data on these 11 road segments were extracted from the so called TRISS[7] database for a total of 2 years, July 2002–June 2004. There are three categories of disturbances: accidents, road/maintenance works and traffic messages. The last includes everything that has caused disturbances, except events of the first two types. Third category events are foremost stopped vehicles, obstacles on the road, dropped cargo etc.

In summary, for all three types of disturbances, it cannot be stated that any type of collision-free road **would function notably worse with respect to transport quality**, when there is a disturbance.

[6] RIT = Royal Institute of Technology, Stockholm (part of Stockholm University)
[7] TRISS = TRaffic Information Support System

7 Investment Costs and National Economy

VTI has collected and compiled data on costs for all rebuilt objects during 1998–2003. The results show a distinct difference between MML and MLV objects. The costs for rebuilding 31 MML object with 2+1 design amounted to **on average SEK 1.43 million per km**. The costs vary from 0.60 million for the least expensive to 2.45 millions for the most expensive.

There is MLV data for 50 objects. The average reconstruction cost is **SEK 2.35 millions per km.** If three objects are excluded, for which rebuilding included widening from 8m to 13m, the cost becomes **2.22 millions per km**. The costs vary from SEK 0.44 to SEK 4.49 millions per km.

An assessment has been made of the effects on national economy of rebuilding to 2+1 road. The conditions are as follows:

1. 13 m road with 7,000 vehicles as AADT and with 100 km/h speed limit. 12% heavy vehicles, which means 7,850 axle pairs per day (24 hours). The road is rebuild to a MLV
2. SMW with AADT 9,000 vehicles and speed limit of 100 km/h. 12% heavy vehicles, which gives 10,200 axle pairs per day. The road is rebuild to a MML
3. The price level of 2006 for all costs and benefits and depreciation time of 40 years.
4. This results in a construction cost for MLV of 2.6 million per km and 1.6 million per km for MML.

The 100 km/h speed limit was chosen since from autumn 2008 this will become the new, "normal" speed limit for 2+1 roads. In order to refine the calculations and describe the **effect of the 2+1-design only**, the speed limit 100 km/h is used for the "zero alternatives", 13 m and SMW respectively.

The societal benefits are assessed according to net present value (NPV) ratio, a measure that also accounts for taxes and fees. (There shall be noted that a NPV-value more than zero is socio-economic profit). The calculations show that the NPV ratios become very high – at the level of **2.3 for MLV and 7.7 for MML designs. This means very high profitability** for 2+1 investments made. The NPV ratios remain high even with a shorter depreciation time of 20 years – 1.4 for MLV and 5.2 for MML.

Better road safety is the major reason for rebuilding to 2+1 road. A commonly used measure to assess road safety effect is the **road safety efficiency value.** This is calculated as the discounted construction investment (capital cost per year) divided by annual decrease in FSI, i.e. the cost to save one FSI per year. Similarly it is possible to estimate the efficiency value for fatalities, i.e. the investment required to save one fatality per year.

The road safety efficiency values are about **SEK 2 millions for MLV and 0.8 million per annual decrease in FSI.** The efficiency value for **fatalities is SEK 7.4 millions for MLV and SEK 2.5 million for MML.** Generally these values are very high and reflect good efficiency. The values for MLV are of the same magnitude as those for ATC[8] investments while the MML values are distinctly lower than those for ATC.

[8] ATC = Automatic Traffic Control (for instance ”speed camers”, now called traffic safety cameras)

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