DESIGN CRITERIA AND TRAFFIC PERFORMANCE RESEARCH IN NEW SWEDISH GUIDELINES ON RURAL HIGHWAYS

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ABSTRACT

The National Swedish Road Administration (NSRA) has recently published new guidelines on geometric design of rural highways. These are based on extensive research on traffic performance, traffic safety, vehicle operating costs and emissions mainly carried out by the Swedish Road and Transport Research Institute (VTI). This paper summarizes design criteria and recommendations in the new NSRA guidelines and the main findings in the VTI research on traffic performance.

The main Swedish cross-sections at normal rural posted speeds of 90 kph and 110 kph are:

- the normal two-lane road:
  9 m with normal traffic lanes 3.75 m and normal hard shoulders 0.75 m with dotted pavement markings
- the wide two-lane road: 13 m with normal traffic lanes 3.75 m and wide hard shoulders, 2.75 m with dotted pavement markings *or* 13 m with wide traffic lanes 5.5 m and normal hard shoulders 1.0 m with solid embossed pavement markings

These cross-sections give very different traffic performance due to varying overtaking behavior. The normal two-lane road operates with a traditional overtaking behavior requiring full use of the opposite lane and free sight distances from 250 m at flying overtakings of cars and upwards to 900 m at accelerating overtakings of trucks with trailer according to the VTI research. The wide two-lane road gives a more efficient "passing behavior". On average 85 % of overtaken and visible oncoming vehicles turn out using the hard shoulder or the full width of the wide lane to give space to an overtaking vehicle creating "three-vehicle passing situations" according to the VTI research. Average car speeds on 13 m roads are higher than the posted speed up to 700 to 1800 veh/h due to alignment standards while 9 m road speeds decrease rapidly around 200 to 500 veh/h. Capacity is estimated to 3000 veh/h for the 13 m road. The 13 m road gives approximately 10% better safety performance than the normal two-lane road.

The 9 m-section is recommended for traffic flows below AADT 2500 the opening year and the 13 m-section for traffic flows above AADT 8000 in flat terrain. In the interval 2500 to 8000 there is a choice between the 9 m-section with increasing demands on overtaking sight distances and frequencies and the 13 m-section with lower demands on passing sight distances.

The design recommendations are based on level-of-service criteria for single drivers and for design hour traffic drivers combined with traffic safety criteria within the framework of a reasonable optimization of life cycle economic costs.

The level-of-service criteria for design hour traffic, normally defined as 12 % of AADT for 20 year traffic, are:

- average link speed including intersection delays, $V \geq VR-10$, where VR = reference speed is the actual or planned posted speed
- average link queuing time in a platoon before overtaking ≤ 5 minutes
- link and intersection degree of saturation $DS \leq 0.5$

The main traffic safety threshold criteria is:

- intersection accident level exceeding 0.5 severity-adjusted accidents/year should be avoided.

INTRODUCTION

The National Swedish Road Administration (NSRA) has recently published new guidelines on geometric design of rural highways (*1*). These are based on extensive research on traffic performance, traffic safety, vehicle operating costs and emissions mainly carried out by the Swedish Road and Transport Research Institute (VTI). The aim of this paper is to summarize design criteria's and recommendations in the new NSRA guidelines and the main findings in the VTI research on traffic performance.

NSRA NEW GUIDELINES

Design Criteria and Economic Values

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The main traffic safety threshold criterion is:

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The life cycle economic cost optimization calculations include travel time, traffic safety, vehicle operating and emission (CH, NOx, CO) costs, construction and maintenance, land acquisition and intrusion costs. The economic costs and values presently used are to be found in Table 1 for time and vehicle operating costs, in Table 2 for accidents costs and in Table 3 for emission costs. All costs are given in Swedish crowns (SEK) in these tables.

Cross-Sections and Alignment

The main Swedish cross-sections on major two-lane rural highways are:

- the normal two-lane road: 9 m with normal traffic lanes 3.75 m and normal hard shoulders 0.75 m with dotted pavement markings
- the wide two-lane road: 13 m with normal traffic lanes 3.75 m and wide hard shoulders 2.75 m with dotted pavement markings *or*
- 13 m with wide traffic lanes 5.5 m and normal hard shoulders 1.0 m with solid embossed pavement markings

Normal posted speeds are 90 kph for the normal two-lane road and 90 or 110 for the wide two-lane road.

Table 1 Time and Vehicle Operating Economic Costs (SEK, taxes excluded 1993-01 and in brackets 1997-01),(*1*)

Time and vehicle operating costs	Time value driver pass.	Commodities	New vehicle	New tire	Petrol	Maint. labor cost	Depre-ciation	Capital costs
Vehicle type	(SEK/h)	(SEK/h)	(kilo SEK per unit)	(SEK per unit)	(SEK/l)	(SEK/h)	(SEK/km)	(SEK/h)
Car	85.5(84)	0	112(159)	435(500)	2.65(2,86)	105	0.34	0.64
Truck	168(168)	10(20)	475(768)	1,200	2.98(2,42)	(120)	1.46	2.71
Articulated truck	168(290)	40(85)	1,100 (2,185)	(1,370)			3.37	6.28

SEK=Swedish crowns

Table 2 Accident Economic Costs per Police Reported Accident (kilo SEK, 1993-01 and in brackets 1997-01), (*2*)

Severity level	Economic costs per injured	Human costs per injured	Non report-correction	Total cost per police reported accident
Fatal	1,100(1,200)	11,000(13,000)	1.0	12,100(14,200)
Severely injured	1,100(1,400)	4,300(4,800)	2.4	5,400(6,200)
Slightly injured	120(140)	110(220)	2.4	230(360)
Damage only	90(90)	10(0)	6.8	100(90)
Average	rural (excluding wilderness accidents)			1,300
	urban			520

SEK=Swedish crowns

Table 3 Emission Economic Costs
(SEK/kg, 1993-01 and in brackets 1997-01), (*1*)

Emission	Rural	Urban
NOx	25(43)	40(60)
HC	15(17)	20(42)
CO_2	0.25(0.38)	0.25(0.38)
SO_2	(16)	(114)
Particulates	(180)	(1,084)

SEK=Swedish crowns

These cross-sections give very different traffic performance due to varying overtaking behavior. The normal two-lane road operates with a traditional overtaking behavior requiring full use of the opposite lane and free sight distances from 250 m at flying overtakings of cars and upwards to 900 m at accelerating overtaking of trucks with trailer. The wide two-lane road gives a more efficient "passing behavior". The overtaken vehicle and a visible oncoming vehicle turn out using the hard shoulder or the full width of the wide lane to give space to an overtaking vehicle creating "three-vehicle passing situations". The formal law obedience of this passing behavior is questioned if the active overtaking vehicle is "forcing its way" and/or is crossing the center line.

Wide two-lane road traffic behavior is treated more deeply in another symposium paper "The Operational and Safety Effects of New Road Types - Experiences from the Nordic Countries."

The guidelines require stopping sight distances and corresponding minimum horizontal (with 5.5 % superelevation) and vertical radii, see Table 4, independent of cross-section, based on a standard safety concept. This means possibility to stop from a travel speed VR+10 (VR posted speed) with 2 seconds perception and reaction time and a braking capacity of on average 2.6 m/s^2 from 120 kph and 2.75 m/s^2 from 100 kph. The braking capacity corresponds with available average frictions on wet surfaces according to NSRA measurements. Standard eye height is 1.1 m located 2.0 (1.0) m from the right (left) hand side of the road with a conspicuity angle of 1/60 grade. The object height varies from 0.2 to 0.6 m located 2.0 m from the road side.

The normal two-lane road is recommended for traffic flows during the opening year below AADT 2500 and the wide two-lane road above AADT 8000 in flat terrain. In the interval 2500 to 8000 there is a choice between the 9 m-section with increasing demands of overtaking sight distances and frequencies, from 500 m once per km to 900 m almost constantly or alternatively with crawling or passing lanes, and the 13 m-section with lower demands on passing sight distances, 350 m.

Full standard motorways with 2*3.75 m traffic lanes, 2.0-2.75 m outer and 1.0-1.5 m inner hard shoulders for 90 kph and 110 kph respectively, equipped with a wide median ($\geq$13 m) or a narrow median (4 m) with a barrier, are recommended from AADT 12000. This standard motorway is also recommended for the national trunk highways Malmö-Stockholm-Gothenburg and a few other links. This national trunk road standard has recently been questioned by the new government. Experiments are therefore prepared to test narrow four-lane divided roads in some cases with at-grade intersections in the flow range AADT 6000-12000.

Support for evaluations of traffic operational effects in feasibility and final design studies are given in the guidelines as for example single vehicle speed profiles, average speeds, see Figure 1, vehicle operating and emission costs, see Figure 2 and 3, and traffic safety, see Table 5.

Table 4 **Alignment Standard Parameters in NSRA Guidelines**

VR kph	Stopping sight distance (m)		Minimum alignment				Overtaking sight (m)		Passing sight
			Horizontal radius		Crest (sag[1]) radius				
	Good	Low	Good	Low	Good	Low	Good	Low	(m)
90	165	135	500	400	7,000 (1550)	5,000 (2200)	900	500	350
110	235	195	800	600	16,000 (2200)	11,000 (1900)			

Good=minimum for new construction with normal costs and intrusion effects
Low=minimum for rehabilitation works with very high costs and high intrusion effects
[1]=comfort value

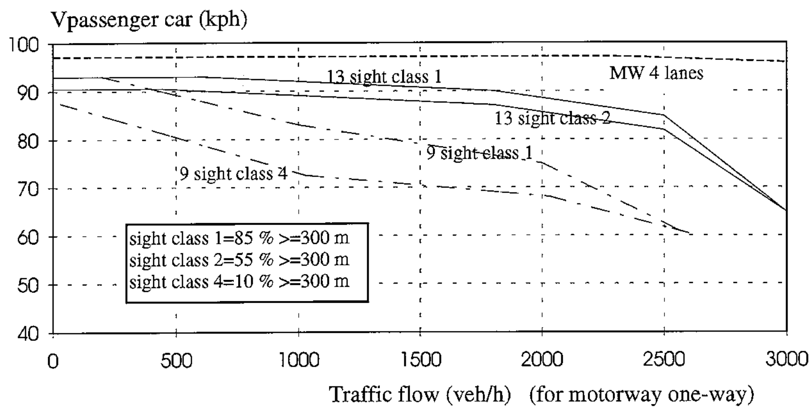


FIGURE 1 Speed / Flow Relationship for 9, 13 M and Motorway Cross-section at 90 Kph, (*1*)

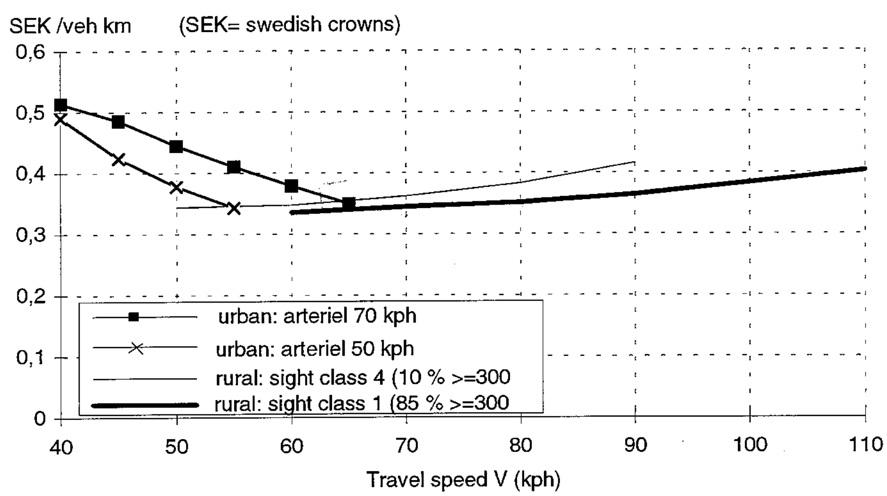
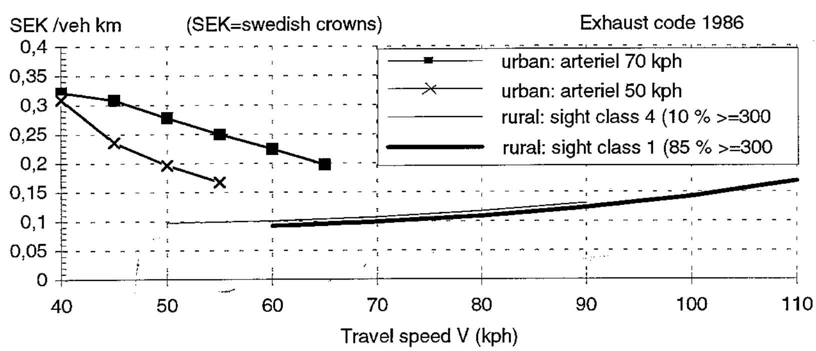


FIGURE 2 Vehicle Operating Costs (SEK/veh km, 1993-01 excluding depreciation and capital costs) **for Passenger Cars on Highways With Varying Standard, (*3*)**

Table 5 Accident Rates AR (Accidents Including Damages Only/m Veh km), **Severity Rates SR** (Injured/accident Including Damages Only) **and Accident Costs AC** (KiloSEK/million Veh km) **for 9, 13 M and Full Standard Motorway Cross-sections at Posted Speed 90 Kph and Varying Sight Classes** (Cost Level 1993-01, Ref *4*). Wilderness Accidents Are Excluded.

	Cross-section Posted speed	Sight class 1 100–70% road length with sight >300 m	2 70–40% road length with sight >300 m	3 40–20% road length with sight >300 m	4 20–0% road length with sight >300 m
Accident rate AR	9-90	0.34	0.35	0.37	0.39
	13-90	0.28	0.29		
	MW-90	0.23			
Severity rate SR	9-90	0.63	0.63	0.63	0.63
	13-90	0.63	0.63		
	MW-90	0.45			
Accident cost AC	9-90	528	544	574	606
	13-90	430	452		
	MW-90	211			



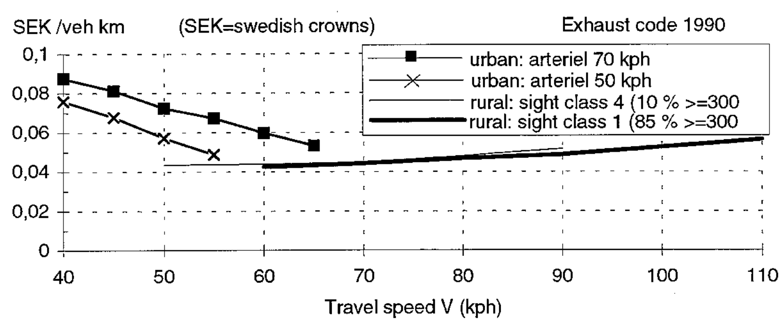


FIGURE 3 Emission Costs (SEK/veh km 1993-01) **for Passenger Cars, Exhaust Code 1986** (top) **and 1990** (bottom), **on Highways with Varying Standard,** (*3*)

The wide two-lane road gives average car speeds higher than the posted speed up to 700 to 1800 veh/h due to alignment standards and a capacity around 3000 veh/h. This can be achieved at a approximately 10 % better safety level than the normal two-lane road. Speeds on 9 m roads decrease rapidly at flows in the interval 200 to 500 veh/h. The big differences between two-lane roads and motorways are driver convenience, traffic safety and construction costs. The accident cost level for motorways is only 50 % of the wide two-lane road. Construction costs for motorways are approximately 50 % higher than for wide two-lane roads. The difference between wide and normal two-lane roads is on average 35 %.

Road Side Areas

The guidelines separate three main road side types depending on safety and drainage conditions:

- Very low risk of fatal injury at run-off accidents. Requires under drains 0.3-0.5 m below formation level. Pavement depth normally between 1 and 2 m, Figure 4a.
- Low risk of fatal injury at run-off-accidents. Could be equipped with under drains or open ditches, Figure 4b.
- Risk of fatal injury. Traditional design with open ditches 0.3 m below foundation level, Figure 4c.

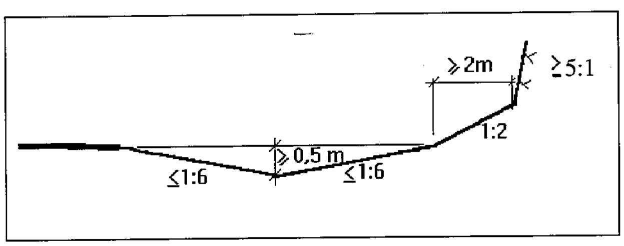


FIGURE 4a Road Side Area Design Type A in Rock Cut

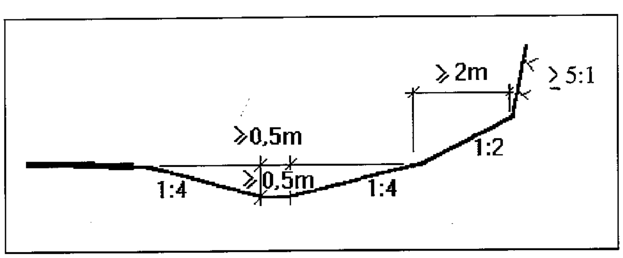


FIGURE 4b Road Side Area Design Type B in Rock Cut

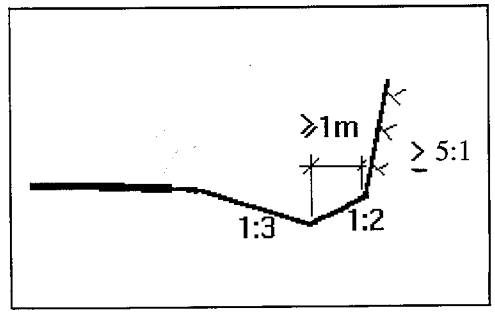


FIGURE 4c Road Side Area Design Type C in Rock Cut

Road side area type A or B is requested on national highways and is recommended for other highways with AADT the opening year higher than 2000-4000 depending on posted speed, cross-section and geographical location. Support for evaluation of traffic safety effects in feasibility and final design studies are given, see Figure 5. The consequence of a run-off accident in a type C rock cut is estimated to be 7-8 times worse than in a type A design. Designs, traffic flow thresholds and safety effect estimates are based on run-off-accident statistics, computer simulation of run-offs and crash test dummy experiments (*5*).

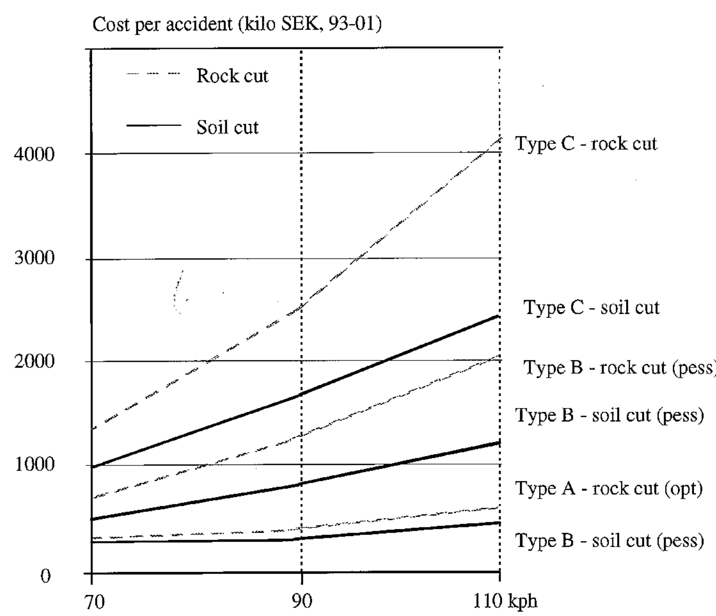


Figure 5 Estimated Traffic Safety Effects on Run-off Accidents (93-01)

Intersections

The guidelines differ between minor and major intersection types, see Figure 6. Minor intersections do not introduce any measures to improve delays or safety for crossing and left-turning drivers from the minor road. Minor intersections are unchannelized (type A), secondary road channelization (B) and primary road left turn lane normally with a ghost island (C). Major intersections are roundabout (D) and grade separation (F). Traffic signals are not used in rural areas due to very bad safety experiences from full-scale experiments in the 80's. Staggered intersections are recommended instead of 4-way intersections and might also compete with major intersection types.

The choice between minor and major intersections is expressed in traffic flow thresholds determined mainly by the traffic safety criteria, see Figure 7.

The choice between grade-separation, roundabout and staggered intersection depends heavily on road function class and local circumstances. Support for evaluations of alternatives is given in the guidelines for traffic operational effects as for example traffic safety, see Figure 8. Minor intersections give very poor traffic safety at high minor road flows (≥ 10% of total incoming traffic).The traffic safety criteria and effects are based on extensive VTI and NSRA research (*6*).

VTI RESEARCH IN TRAFFIC PERFORMANCE

Overview

VTI has carried out a lot of research in the field of traffic performance, traffic safety, vehicle operating costs and emissions to support the new NSRA design and feasibility study guidelines. The main results for feasibility studies are summarized in the NSRA "Traffic effects catalogue" (*2*). This paper concentrates on the traffic performance research, especially on 9 and 13 m roads (*7*). This research was carried out in 4 steps:

- an empirical study of overtaking behavior on 9 m and 13 m roads
- an empirical speed-flow investigation on motorways
- development of traffic and geometry related level-of-service measures for 9 and 13 m roads with varying sight conditions using the VTI simulation model (*8*)
- estimating speed-flow relations for varying cross-sections, speed-limits and surroundings using the VTI simulation model.

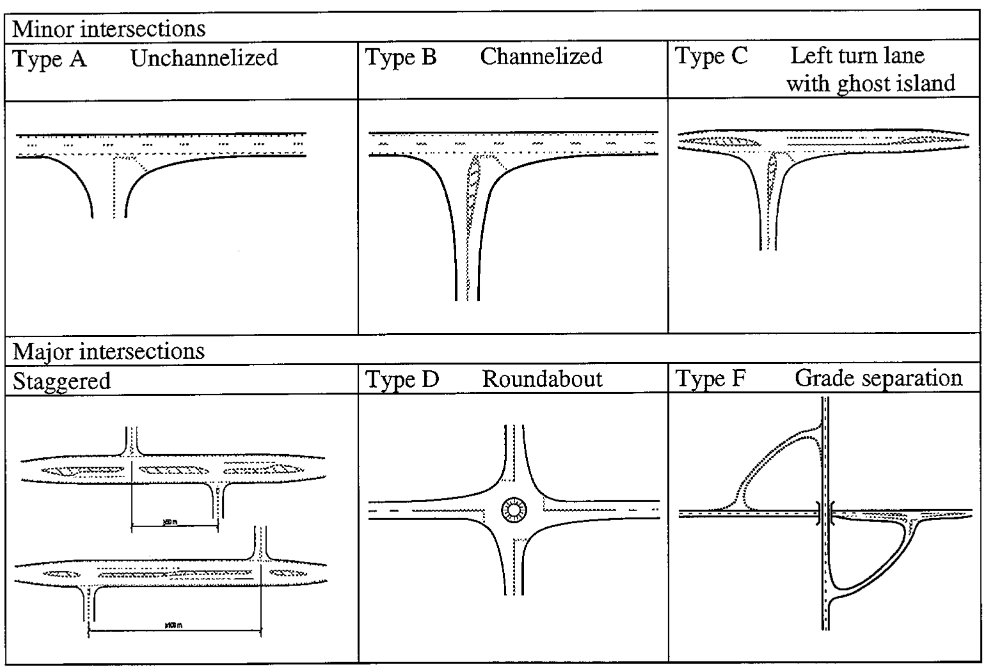


FIGURE 6 Minor and Major Intersection Types in Rural Areas

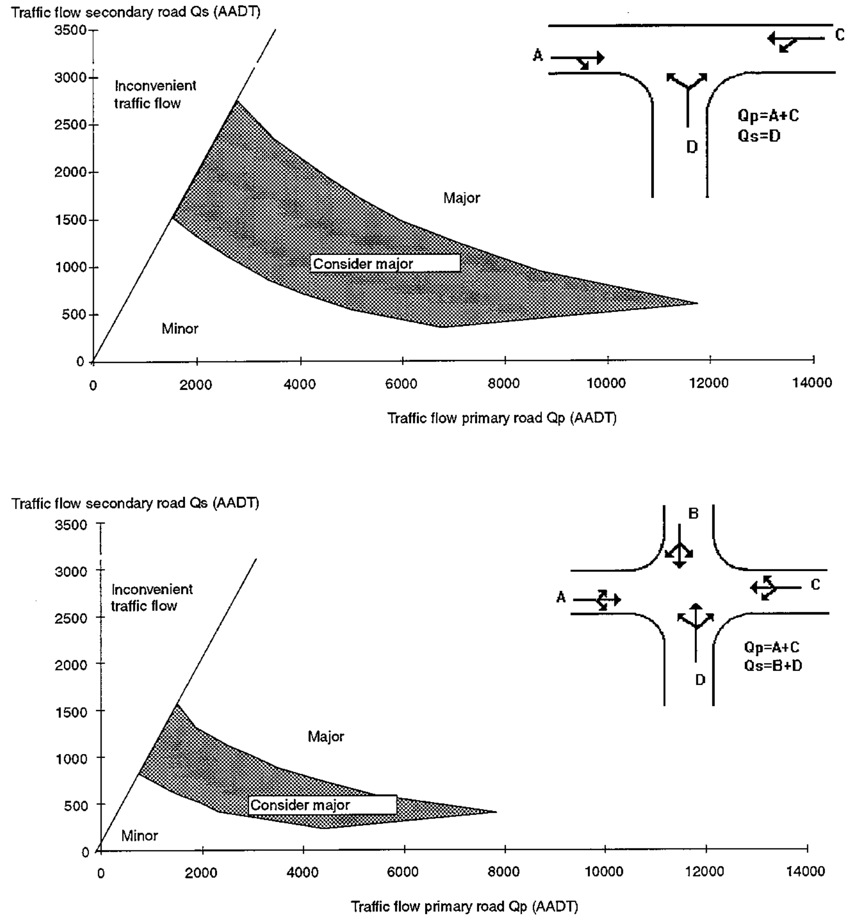


FIGURE 7 Traffic Flow - Traffic Safety Criteria for Choice Between Minor and Major Intersection, 3-way Intersections (top) **and 4-way Intersections** (bottom)

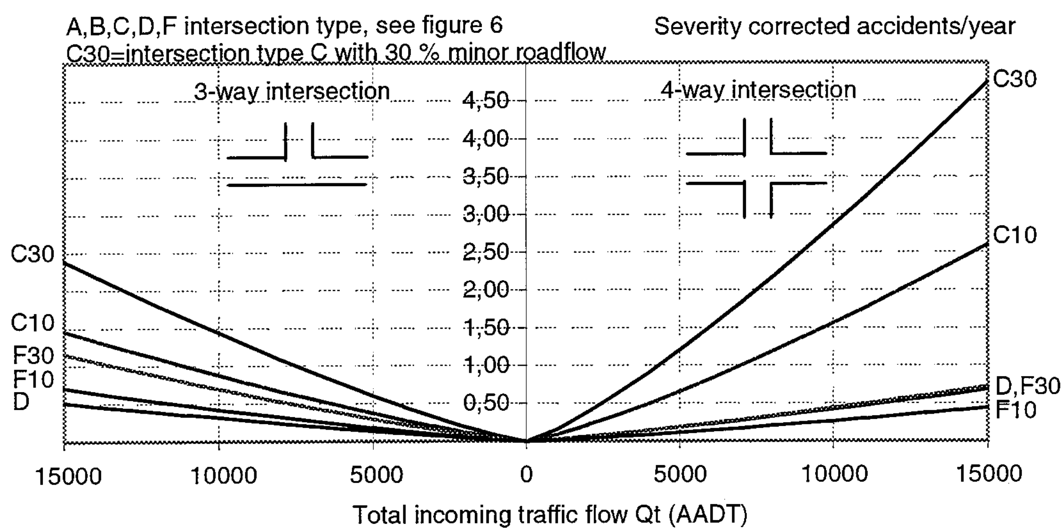


FIGURE 8 Severity Corrected Accident Rates (93-01) **per year and Intersection Type on Rural Highways at 90 kph** (wilderness accidents excluded)

The aim of the empirical study was to investigate how overtaking behavior is influenced by cross-section, available sight distance, actual speeds, vehicle types and traffic flow on 2-lane roads. The survey was carried out using video recordings from a helicopter. The video recordings were manually analyzed regarding overtaking behavior and shoulder driving in passing situations.

Data was collected from 4 field sites with 9 m and 4 sites with 13 m cross-sections. The survey time varied from 2 to 4 hours at each site. The 9 m as well as the 13 m field sites had AADTs from 5000 to 10000. The actual hourly survey flows were 500-1200 veh/h for the 9 m sites and 200-1400 veh/h for the 13 m sites. Approximately 2000 passing situations with shoulder driving and 500 normal overtaking situations with sight distances from 200 m and upwards were registered on the 13 m sites. For the 9 m sites approximately 2000 overtaking situations were measured.

In the data analysis, probability functions were created for different types of overtaking, which indicate the probability of an initiated overtaking as a function of the available sight distance. Overtaking behavior and probability function depends on type of overtaking (flying or accelerating), speed and type of overtaken vehicle (car above or below 90 kph, truck with or without trailer) and also on sight hindrance (terrain or oncoming visible vehicle). These new probability functions (totally 32) have replaced earlier functions used in the VTI's traffic simulation model for rural roads.

The sight design analysis consists of a large series of simulations in low and high traffic flows on 9 m and 13 m cross-sections with varying sight distance profiles. The alignment of the simulated road was rather flat with posted speed 90 kph. The sight distance profiles were created using sight distance maxima 400 m, 600 m, 800 m and 1000 m with frequencies 0.5, 1 and 2 times per km of road length, (also 3 times per km for the 400 m maxima). These sight designs were also classified according to the sight class system used in the traditional NSRA planning model. This classification is based on the proportion of sight distances above 300 m along the road, see Table 5. Table 6 gives a detailed description of all sight distance designs with corresponding sight classes used in the simulations. For each simulation a number of traffic performance measures such as journey speed, proportion of journey time delayed, overtaking frequencies and average queuing (tailing) time in platoons were calculated.

Results of Empirical Studies on 13 m Roads

The main finding on 13 m roads is the high proportion of vehicles using the wide hard shoulder when caught up to facilitate passing. The results show that in daylight on average 85 % of caught-up vehicles (both cars and trucks) turn out on the shoulder.

This indicates that situations with three vehicles very close to each other involved in a passing maneuver are frequent. At one field site as much as 66 % of all passings where such "three-vehicle passing situations". This behavior is questionable due to how the Swedish traffic code is interpreted. The use of the shoulder in passing situations does not vary with available sight distances or sight hindrance type. The background for the demand of 350 m as minimum sight distances in the new guidelines for a 13 m road is a passing safety concept.

In cases where a caught-up vehicle does not use the shoulder an ordinary overtaking has to be performed. The results show that overtakings are fulfilled at rather short overtaking sight distances in daylight. As an average for all ordinary overtakings 50 % of the drivers accept a free sight distance of 240 m when overtaking a car. But the value for flying overtakings is just 190 m and for accelerated overtakings with an oncoming visible vehicle 360 m.

The corresponding values for overtaking a truck with trailer is about 325 m as an average. For a flying overtaking of a truck with trailer the value is 205 m and for an accelerating one with oncoming visible vehicle it is 520 m.

For traffic in darkness the behavior is different. The use of hard shoulders decreases. A simple manual study showed that only about 30 % of the cars and 40 % of the trucks drove on the shoulder in catching-up situations.

Results of Empirical Studies on 9 m Roads

The 9 m roads have, as already mentioned, a quite different overtaking behavior compared with the 13 m road. There is a pronounced demand for longer free sight distances at overtaking. Briefly the average results of all overtakings show that, when overtaking a car 50 % of the drivers accept a free sight distance of 440–510 m, depending on the speed of the caught up vehicle. For overtaking of a truck, drivers need further free sight distances, about 500 m for a truck without trailer and 590 m for a truck with trailer as an average.

Figure 9 presents the differences in demands for overtaking sight lengths on 9 m and 13 m roads for overtakings of different kind of vehicles. It clearly shows that more careful drivers (the 85-percentile curve) on 9 m roads require free sight distances in the range 700–900 m. This is the reason why the new guidelines recommend sight distances of up to 900 m.

Table 6 Description of Sight Distance Designs Used for Simulation

Sight distance max m	No of max per km	Proportion of sight distance above 300 m %	Sightclass
1000	2	100	I
	1	70	II
	0.5	35	III
800	2	100	I
	1	50	II
	0.5	25	III
600	2	60	II
	1	30	III
	0.5	15	IV
400	3	30	III
	2	20	IV
	1	10	IV

Table 7 50 and 85 Percentiles Overtaking Sight Distances for Different Types of Overtaking on 9 m Roads

Vehicle type	Overtaking type	Sight distance (m) 50 pctl	Sight distance (m) 85 pctl
Overtaking cars	Flying, no oncoming	232	351
	Flying, with oncoming	284	431
Overtaking trucks	Flying, no oncoming	269	367
	Flying, with oncoming	325	482
Overtaking car, speed < 90 (kph)	Accelerating no oncoming	508	943
	Accelerating with oncoming	643	980
Overtaking car, speed > 90 (kph)	Accelerating no oncoming	576	1 033
	Accelerating with oncoming	693	1 056
Overtaking truck, no trailer	Accelerating no oncoming	548	893
	Accelerating with oncoming	700	1 060
Overtaking truck, with trailer	Accelerating no oncoming	695	1 133
	Accelerating with oncoming	852	1 263

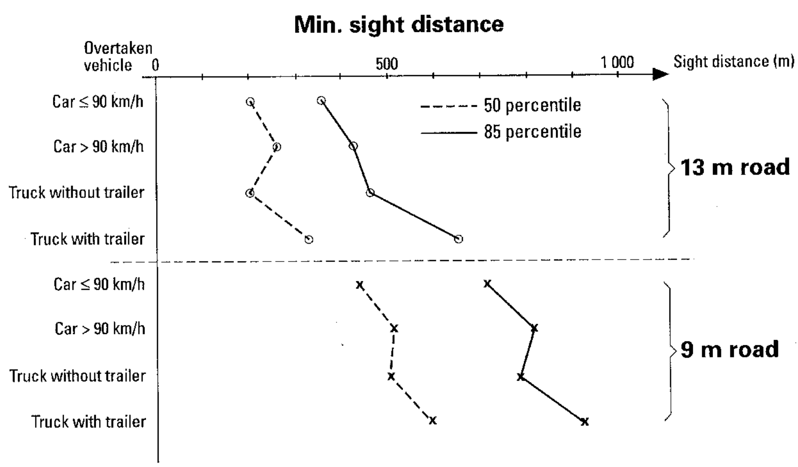


FIGURE 9 Measured Overtaking Sight Distances on 13 m and 9 m Roads

Furthermore on this type of road there is a very pronounced difference in demand of free sight distances between different types of overtakings, especially between flying and accelerating overtakings and also due to sight hindrance type. Table 7 presents overtaking sight distance demands for all kinds of overtakings on 9 m roads. The Table shows both the 50-percentile and the 85-percentile of the drivers.

From Table 7 one can observe that for a flying overtaking of a car without visible oncoming vehicle the 50-percentile value is 230 m. The corresponding value for an accelerating overtaking of a car, with speed above 90 kph and with visible oncoming vehicle, is 690 m. (The average for all overtakings together is 510 m.)

For flying overtaking of a truck with trailer without visible oncoming vehicle the 50-percentile value is 270 m and for accelerated overtakings with visible oncoming vehicle the same value is 850 m (average for all overtakings is 590 m).

Results of Simulation on 13 m Roads

From the simulations the following traffic performance measures have been analyzed:

1. Journey (travel) speed for cars and trucks measured as space mean speed over the simulated road segment.
2. Overtaking ratio for cars. This is the number of overtakings performed by cars divided with the number of car km over the road segment.
3. Proportion of journey time delayed for cars and trucks. This is the level of service measure used in HCM (LoS). Delayed was defined as headway less than 6 seconds.
4. Average queuing (tailing) time in a platoon for cars. This is the average time a car is driving in a platoon before an accelerated overtaking is performed. (This measure is not calculated on 13 m roads, just for 9 m roads.)

For each measure an average value for the simulated road in each sight class has been calculated at different traffic flows. However sight class IV design in Table 6 was not simulated for the 13 m roads.

The results of the simulations on 13 m road prove that this road type has a very good traffic performance, regardless of sight design. Even at the traffic volume 1600 veh/h, the travel speed for cars is over 90 kph, see Figure 10. The overtaking ratio is high and mainly constantly increasing with traffic volume. The proportion of travel time delayed is low and only about 15 % at 1600 veh/h, also when the sight conditions are fairly bad, see Figures 11 and 12.

These simulation results are in good agreement with empirical data on 13 m roads, where VTI has measured speeds and overtaking rates in traffic flows up to 1500 veh/h.

Results of Simulations on 9 m Roads

The same traffic effects have been analyzed from the simulations on 9 m roads.

On the 9 m roads, the traffic performance depends largely on the sight design. For example to achieve a travel speed for cars of 80 kph at the flow 700 veh/h the sight design sight must be at least class II. That means on average 55 % of the road length must have sight distance above 300 m, see Figure 13. At these conditions the proportion of travel time delayed is somewhat less than 60 % (LoS C), see Figure 14.

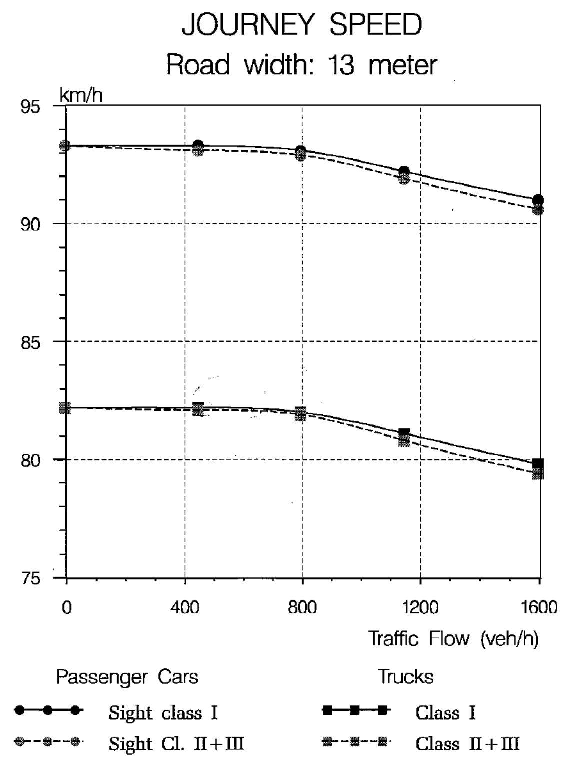


FIGURE 10 Simulated Journey Speed for Cars and Trucks as Function of Traffic Flow - 13 m Road

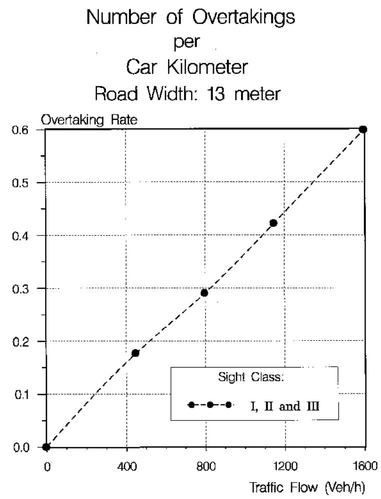


FIGURE 11 Simulated Overtaking Ratio for Cars as Function of Traffic Flow - 13 m Road

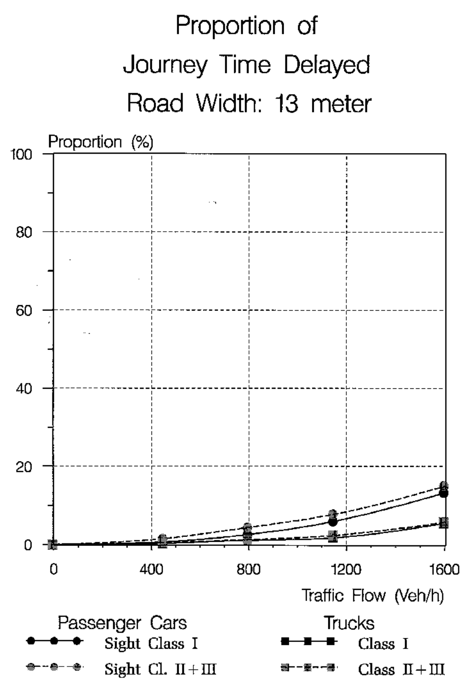


FIGURE 12 Proportion of Journey Time Delayed for Cars and Trucks as Function of Traffic Flow - 13 m Road

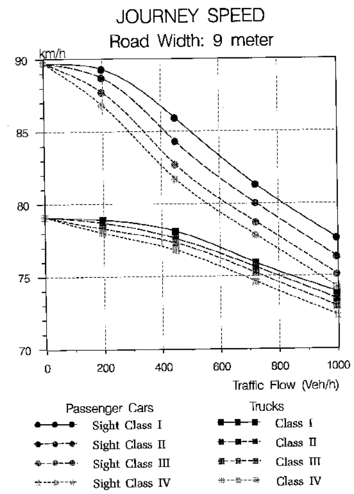


FIGURE 13 Simulated Journey Speed for Cars and Trucks as Function of Traffic Flow - 9 m Road

At a flow over 1000 veh/h, the travel speed for cars is clearly below 80 kph, regardless of sight design. The proportion of travel time delayed is over 60% (LoS D). At these traffic volumes the queuing time is fairly high, at least 8 min for sight class I, see Figure 15.

Evaluations of the Simulations

To evaluate the results presented in Figures 10–15, a number of criteria were proposed for defining an efficient traffic performance. These criteria are as follows:

1. The travel speed for cars must be 80 kph or higher ($V \geq VR-10$).
2. The proportion of travel time delayed for cars should not exceed 60–65 % (the lower part of LoS D).
3. The average queuing time for cars in a platoon should not exceed 5.0 minutes. This means a trip length of 6.5–7 km at a speed of about 80 kph.

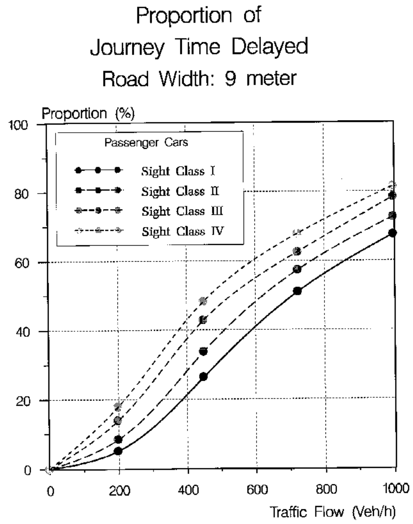


FIGURE 14 Proportion of Journey Time Delayed for Cars andTrucks as Function of Traffic Flow - 9 m Road

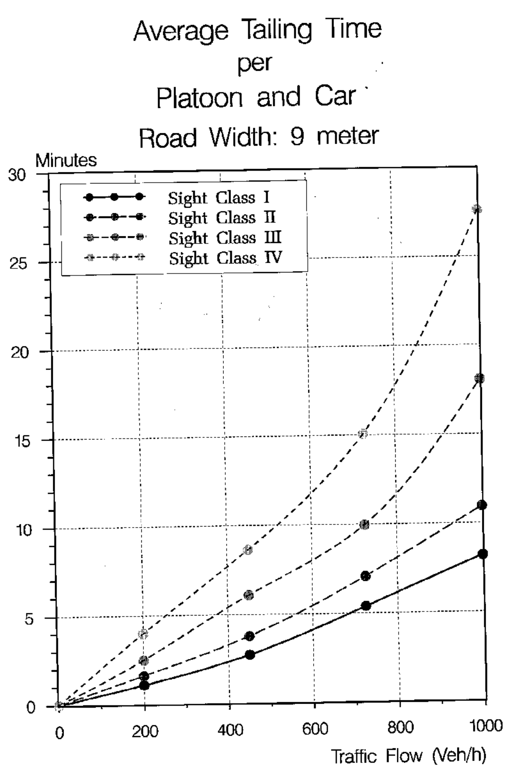


FIGURE 15 Average Tailing Time in Platoons for Constrained Cars - 9 m Road

As an application of the criteria we consider an AADT of 7000 vehicles, for a 9 m road. The design hour traffic is then 840 veh/h. The following summarizes the effects at this flow, in sight class I:

Travel speed 79.8 kph (from Figure 13)
Prop of travel time delayed 58 % (from Figure 14)
Queuing time 6.5 min (from Figure 15).

Two criteria out of three for efficient traffic performance are fulfilled. The criterion for queuing time is not fulfilled, but if the sight design is **extremely** good (all sight lengths between 600 m and 1000 m) the queuing time will be reduced to about 5 min.

All the results presented above are for a normal vehicle composition with about 10–15 % trucks. If the proportion is higher or lower, travel speeds for cars are modified using adjustment factors, determined by simulations with high and low proportions of trucks. This method with adjustment factors is used instead of pcu-values.

PROPOSAL FOR GENERAL DESIGN GUIDELINES

On basis of the proposed performance criteria, the traffic simulations and the empirical study the following general design guide lines for 9 m and 13 m roads were proposed by the VTI.

Roads with AADTs over 7000 vehicles should normally be built with a width of 13 m. The minimum sight distance along the road should be high, preferably not less than 350–400 m.

For an AADT range of 5000–7000 vehicles, a 9 m road can be chosen. In this case, the sight design must be very good and well-planned. At an AADT of 5000 vehicles, a good sight class I design must be chosen with 70–90 % sight over 300 m. In addition, long sight distance maxima of 800–900 m must be provided on the average at least once per kilometer.

At an AADT approaching 7000 vehicles, the sight design must be extremely good. All sight distances should be over 500 m and in addition sight maxima up to 1000 m must be provided. Also in this case the frequency of the sight maxima must be high, with 1.5 to 2 per kilometer.

At an AADT of 3000 vehicles on a 9 m road, the requirements on sight design can be reduced and still satisfy the criteria set. Here, sight class II with 50–60 % sight over 300 m is acceptable. This means one long sight maximum per kilometer with a length of about 800 m or two shorter maxima with a length of 500–550 m.

If the sight requirements on a 9 m road cannot be met, climbing lanes can be provided as an alternative. These should be at least 1.5 km long.

The proposed criteria and design situations illustrate how "functional traffic performance criteria" can be applied to a road.

The criteria and design traffic situations are proposed as examples. Other types and values of criteria, e.g., for minimizing the frequency of uncontrolled three-vehicle passing situations on 13 m roads, may result in different width and sight design proposals.

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