2+1-roads Recent Swedish Capacity and Level-of-Service Experience

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Abstract
The first Swedish 2+1 median barrier road was opened in 1998. The concept was to retrofit the standard existing two-lane 13 m paved width cross-section at 90 and 110 kph posted speed limit without widening. This design has one continuous lane in each direction, a middle lane changing direction every one to three kilometres with a median barrier separating the two traffic directions. Today over 2 700 km 2+1 median barrier roads are opened for traffic. AADT’s vary from some 3 000 to 20 000 with an average just below 10 000 nowadays normally with 100 kph.

The concept has lately been enhanced also to cover the existing 9 m paved width cross-section. The design concept is the same from a driver’s viewpoint, one continuous lane in each direction with a middle lane changing direction and a separating median barrier. This is created by introducing a continuous median barrier and adding overtaking lanes within an overtaking strategy. The differences are the existence of 1+1-sections, less overtaking opportunities and a slightly more narrow cross-section. Some 15 projects are opened.

The purpose of this paper is to summarize present knowledge on level-of-service issues as they are presented in Swedish design and assessment guidelines and to give an overview of field measurements and theoretical analytical and simulation studies supporting the recommendations.

Keywords: 2+1 median barrier roads, capacity, level of service

1 Introduction

The Swedish trunk road system was extended and improved rapidly from the early 50’ies until the late 90’ies using basically four road types:
normal two lane roads (8-9 m paved width) with at grade intersections with posted speed limits 70 or 90 kph and sometimes in Northern Sweden 110 kph

- wide two lane roads (12-13 m paved width) with grade-separated intersections, full access control and pedestrians, bicyclists and slow moving vehicles forbidden, denoted semi-motorways normally with posted speed limits 110 kph

- wide two lane roads (12-13 m paved width) with grade-separated intersections, a lot of accesses and pedestrians, bicyclists and slow moving vehicles allowed normally with posted speed limits 90 kph in Southern and 110 kph in Northern Sweden

- motorways normally with 110 kph

Truck speed limits are 80 kph with the exception 90 kph on motorways and semi-motorways. Bus speed limits are 90 kph and for seat-belt equipped buses 100 kph. Shoulder bearing capacities on wide two lane roads varied due to age with full strength from the mid 80’s constructions. Two cross-section designs were used, with 2.75 m wide hard shoulders and 3.75 m lanes and with narrow hard, 1.0 m, shoulders and wide lanes, 5.5 m. There were some 3 600 km representing 14 % of the trunk road system in length and 26 % in mileage with AADTs from 2 000 to some 20 000.

More reliable accident data by road type became available during the 80’s revealing wide two-lane roads and especially semi-motorways to have the worst safety records of all road types in terms of fatalities and severe injuries. Almost 100 out of a total toll of 400 per year on state roads were killed on these wide two-lane roads with an extreme fatality risk especially at 110 kph around 0.015 per Million axle pair km (including intersections excluding wildlife accidents).

Steadily higher political focus on safety created an in-house Swedish Road Administration proposal to improve safety using a low-cost 2+1 median barrier concept on these wide two lane roads, see Figure 1. The central median barrier winds between the traffic directions with a central lane changing traffic direction on average every one to three km and one continuous lane in each direction squeezed into the 13 m formation. This challenged more or less all traditional highway engineering paradigm. Intersections are normally located at transitions. Some parallel roads are added to take away some accesses and to improve conditions for pedestrians and bicyclists. The 0.75 m hard shoulder is considered acceptable for bicyclists and pedestrians.

The same road type without a median barrier had been used occasionally in Sweden and elsewhere, e.g. France, New Zealand and Australia. Germany developed this concept in parallel to a standard design.

Similar road designs with single lane road segments and periodic overtaking lanes have later been proposed and applied around the world including two-lane expressways (Catbagan and Nakamura, 2006) and super 2 highways (Brewer et al., 2012, Brewer et al., 2011).

There were a lot of critical views on the proposal concerning among other issues different aspects of level-of-service. The first road was opened in the autumn 1998. Today there are more than 2 700 km 2+1 median barrier roads in Sweden covering some 14 % of the total Swedish state mileage with a

Figure 1: Typical 2+1 median barrier design on 12-13 m road
history of impressing safety success, some 80 to 90 % fatality reduction, and also mainly positive level-of-service findings. The fatality reduction without barrier according to Swedish experience is minor.

Lately the concept has been used also on existing 9-10 m two lane roads by adding overtaking lanes and median barriers without any widening of the interconnecting 1+1-sections, see Figure 2. There are now some 15 roads opened with this design with overtaking lane percentages down to 15 % compared with normally 40 % for the “traditional” concept and thus also much longer 1+1-sections. A general speed limit review was carried out in 2008 and 2009. The aim for these median barrier roads was to change speed limits from 90 and 110 kph to 100 kph in order to improve the society acceptance of the speed limit system.

![Figure 2: Typical 1+1-section design](image)

The purpose of this paper is to summarize present knowledge on level-of-service issues as they are presented in the Swedish design and assessment guidelines and to give an overview of field measurements and theoretical analytical and simulation studies supporting the recommendations. The paper is organized as follows. Section 2 gives an overview of the current Swedish speed limit system. The present Swedish speed-flow model for estimation of level of service on 2+1 roads is described in section 3 and the current design guidelines is presented in section 4. Section 5 describes the traffic behaviour on 2+1 roads including a summary of results and conclusions from a range of field studies. Results from investigations of overtaking lane percentages, truck shares and segment lengths is presented in section 6. Section 7 presents effects of emergency stops and accidents. Section 8 ends the paper with conclusions and further research needs.

## 2 New speed limit system

The Swedish speed limit system was implemented in the early 70’ies. The general rural speed limit became 70 kph with a power given to the Director General of the Swedish Road Administration (SRA) to increase to 90 or 110 kph based on an assessment of level-of-service, safety and environment. At that time reasonable two lane roads became 90 and “good ones” 110 kph based on width and alignment.

The pressure for a systematic overview of speed limits grew stronger during the 90’ies with the Zero Vision and also the climate change discussion. SRA presented a speed strategy proposal in 2005 (Vägverket, 2005) leading to a major, stepwise national speed limit review with the first major change in 2008 and 2009. Part of this step was to harmonise 2+1 median barrier road speed limits to 100 kph. Today 70 % are 100 kph, 15 % 110 kph due to long distance traffic and 15 % lower than 100 kph due to local restrictions.

A before-after study was done on 2+1 median barrier roads (Vadeby and Forsman, 2010) on 17 projects on one lane segments due to measure technical reasons. Mean and 85 percentile results are shown below. Car speed effects are significant in the magnitude 2 to 3 kph with a tendency to be larger at speed limit increases.
Spot speed data (Olstam et al 2013) for existing 2+1 median barrier roads with speed limits 90, 100 and 110 kph for cars give for free flows 91.5, 96 and 102 kph, i.e. substantially larger differences. This could partly be explained by the flow effect.

### Table 1: Before after results for speed limit changes on 2+1:s

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Before Limit</th>
<th>After Limit</th>
<th>*Sign</th>
<th>85 perc Before</th>
<th>After</th>
<th>*Sign</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cars</td>
<td>110 to 100</td>
<td>102.3</td>
<td>-2.3</td>
<td>yes</td>
<td>117.2</td>
<td>-3.3</td>
</tr>
<tr>
<td></td>
<td>90 to 100</td>
<td>93.8</td>
<td>3.4</td>
<td>yes</td>
<td>104.7</td>
<td>3.1</td>
</tr>
<tr>
<td>Rigid Truck</td>
<td>110 to 100</td>
<td>92.4</td>
<td>-0.5</td>
<td>yes</td>
<td>106.7</td>
<td>-1.9</td>
</tr>
<tr>
<td></td>
<td>90 to 100</td>
<td>89.1</td>
<td>1.9</td>
<td>yes</td>
<td>99</td>
<td>3.2</td>
</tr>
<tr>
<td>Art. Truck</td>
<td>110 to 100</td>
<td>84.7</td>
<td>-0.5</td>
<td>yes</td>
<td>90.1</td>
<td>-0.3</td>
</tr>
<tr>
<td></td>
<td>90 to 100</td>
<td>84.3</td>
<td>0.2</td>
<td>yes</td>
<td>89.4</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Rigid truck = axle distance over 3.5 m

3 Present speed-flow curves and capacities in assessment guidelines and capacity manual

The HCM LOS-concept has never been adopted in Swedish planning and design procedures (Trafikverket, 2014b). The general principle is to choose the alternative concerning cross-sections, speed limits and intersection types giving the best cost-benefit-ratio over 40 years with a 3.5 % interest. There is also an objective that the degree of saturation should preferably not exceed 0.8 year 20 after traffic opening. The latter could be interpreted as a level-of-service measure.

Travel costs are then an essential part of the socio economic costs to be estimated using speed-flow curves on an hourly, one-directional basis (Trafikverket, 2014a). These curves are given for passenger cars (including with trailers), rigid trucks (including buses) and articulated trucks for numerous road types and settings. Rigid trucks are defined as rigid vehicles with axle distances over 3.5 m.

Passenger car (including with trailers) speeds at good alignment for a normal two-lane road with 80 kph and 90 kph, for a 2+1 median barrier road 100 kph with 40 % two-lane and for a 4 lane motorway 110 kph by direction are given below as an example.

![Image](Figure 3 Example of speed-flow relationships at good alignment for passenger cars for a normal two-lane road with 80 kph, and 90 kph, for a 2+1 median barrier road 100 kph with 40 % two-lane and for a 4 lane motorway by direction.)

There are obvious substantial travel time benefits due to higher speed limits for the 2+1. The 2+1, even at the same speed limit, give higher free flow speeds and better performance at directional flows.
up to some 1 000 v/h. Capacity, though, is estimated to be around 1 500-1 600 v/h and direction, some 20 % less than on the normal, 8-10 m paved, two lane. Speed-flow relationships for 2+1 are obviously highly dependent on overtaking lane percentages, see Figure 4. There is judged to be no impact of cross-section and no impact of overtaking lane availability on capacity. Alignment class change from 1 to 2 shifts the curve approximately 1.5 kph.

Figure 4: Overtaking lane percentage and alignment class impact on 2+1 median barrier road 100 kph.

These speed-flow curves and capacities are based on a combination of engineering assessment and empirical data, analytical modelling and simulations, described in chapter 4 and onwards.

4 Design guidelines

Cross-section designs are reported in section 1. Differences in cross-section as shown above are, based on existing research, judged not to impact free flow speeds and capacity. There is an obvious impact of the percentage of overtaking lane as illustrated in Figure 4. There are, though, no recommendations on the choice of overtaking percentages. This is a part of the assessment process described above.

The design guidelines (Trafikverket, 2014b) recommend overtaking sections to be 1 to 2.5 km long. There is also a more specific recommendation on section length due to overtaking lane percentage and flow. This is based on simulations described in section 6 with the criteria to minimise an assumed peak hour delay.

<table>
<thead>
<tr>
<th>Overtaking %</th>
<th>AADT</th>
<th>Overtaking section length m</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>&lt;2400</td>
<td>9-1200</td>
</tr>
<tr>
<td></td>
<td>2400-10000</td>
<td>1200</td>
</tr>
<tr>
<td>20</td>
<td>&lt;9300</td>
<td>9-1200</td>
</tr>
<tr>
<td></td>
<td>9300-10000</td>
<td>1500</td>
</tr>
<tr>
<td>30</td>
<td>&lt;5200</td>
<td>1200-2000</td>
</tr>
<tr>
<td></td>
<td>5200-10000</td>
<td>2000</td>
</tr>
<tr>
<td></td>
<td>10000-13500</td>
<td>1500-2000</td>
</tr>
<tr>
<td></td>
<td>13500-15000</td>
<td>2000</td>
</tr>
<tr>
<td>40</td>
<td>&lt;15000</td>
<td>2000</td>
</tr>
</tbody>
</table>

Table 2: Overtaking length recommendations due to delays
There was also in the beginning a discussion on the design of the termination section due to safety and capacity. The design used is dynamic, smoother than the German design, see Figure 5, with a 400 m pre-warning sign and a lane change sign at the start of 150 m long taper. The guard-rail reflector pattern and interval is also changed.

An alternative design with overhead lane configuration signs to improve conspicuity was tested on E22 Blekinge in a before-after study also with comparisons with results with the standard design on E4 Gävle (Carlsson, 1999) using driver behaviour parameters such as volumes and late lane changes. The overall conclusion was the standard design to be sufficient with no obvious improvements for the overhead signs in terms of safety or traffic performance. Barrier crash data does not indicate transitions to be a problem though bus and truck drivers tend to complain on “chicken race”. Other important design issues are access and vulnerable road user management not discussed further in this paper. Normally some parallel roads are introduced.

5 Traffic behaviour and level of service on 2+1 roads

One major difference between a 2+1-road and a two lane road is overtaking opportunities, restricted to overtaking lanes or continuous due to on-coming traffic and sight distances. Capacity is defined by the transition from two to one lane or by slow moving vehicles on one lane sections. As can be seen in Figure 6 the speed varies along a road with a 2+1 design. Platoons are built up during the one lane segments, since there are no overtaking possibility. How long the platoons become depends to a large extent on the following aspects:

- Traffic flow – especially slow moving vehicles,
- The length of the one lane segment and alignment,
- The variation in desired speed.

Figure 6 shows an example on how the average speed varies along a 2+1 road stretch. During the one lane segment the average speed decrease along the one lane segment due to faster vehicles catching up with slower one. Trucks and buses normally have lower speed limits and desired speeds than cars, thus the average speed for these vehicle types are influenced less. When a two lane section starts, overtaking and discharge of the queues built up along the one lane segments starts to increase the average speed significantly. At the end of the two lane segment the speed decreases again due to the merging of the two lanes.
The speed-flow curves used in the assessment procedure for 2+1 roads were developed based on the results from several field studies (Carlsson, 1999, Carlsson, 2009, Carlsson and Brude, 2003, Olstam et al., 2013, Bergh and Carlsson, 1999, Bergh and Carlsson, 2005) and calculation using analytical models for estimation of delay on one lane segments (Carlsson et al., 2013, Wiklund et al., 2015) and traffic simulations (Robertson and Tapani, 2009). The model behind the speed-flow curves is summarized below:

- The capacity is always estimated to be 1 550 v/h and the speed at capacity is estimated to be 79 km/h (Speed limit range: 80 – 110 km/h). The capacity is determined by the merge from two to one lane with a density at capacity at $\frac{1550}{79} = 19.6$ v/km, corresponding to an average space headway of 51 m. A summary of the field trials behind the capacity estimations is presented later in this section.
- The breakdown is rapid and the speed drops fast from 1500 v/h to the capacity at 1550 v/h. A summary of field trials behind the capacity estimations is presented later in this section.
- The travel speed is assumed to be equal to the free flow travel speed up to a flow level corresponding to $\alpha \cdot 1500$, where $\alpha$ is the share of two lane segments. The limit $\alpha = 1$ (100 % two lane) will the travel speed be assumed to be equal to the free flow speed for flow levels up to 1 500 f/h (i.e. similar as on motorways, cf. the 85% case in Figure 4 and the motorway case in Figure 3).
- The travel speed before the breakdown at flow level 1500 v/h is determined based on calculations of the delay on one lane segments using the model presented in (Carlsson et al., 2013, Wiklund et al., 2015) together with empirical findings on the increase in travel speed on two lane segments.
- For flow levels above $\alpha \cdot 1500$ and below the start of the breakdown 1 500 v/h the travel speed decrease with increasing flow depend on the share of two lane segment in such a way that the speed-flow curve is convex (as for motorways) for high $\alpha$ levels and concave (as for two lane rural roads) for low levels of $\alpha$, see Figure 4 for example of speed-flow curves for different levels of two lane segment ($\alpha$).

Field studies on 2+1 effects on speed and level-of-service has foremost been analysed for two semi-motorway objects:

- a number of before and after spot speed measurements and floating car studies in high traffic volumes (Carlsson and Brude, 2003, Carlsson, 2009)
Some spot speed measurements have been undertaken on some other roads using before-after studies. The main conclusions from measurements on roads with speed limit 90 kph and speed limit 110 kph are (Bergh and Carlsson, 1999, Bergh and Carlsson, 2005, Carlsson, 2009):

- average journey speeds for cars increased some 2 kph at speed limit 90 kph on semi-motorways retrofitted to 2+1
- average journey car speed at 2+1 110 kph was 108.5 kph with a 5 kph speed difference between one- and two-lane segments.
- overtaking lane car speeds were in average 120 kph at low volumes.
- directional flows over 500 v/h create minor and over 900 v/h considerable variations in speed profiles for individual vehicles
- floating car studies confirm a good level-of-service at high traffic flows, up to 1 300-1 400 v/h in one direction and 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 semi-motorway, see Olstam and Carlsson (2014) for details.

These results are illustrated in Figure 7 showing speed data from the beginning of a one-lane segment just downstream a 2 to 1 transition zone at E18 Västerås, a semi-motorway with speed limit 90 kph and a AADT around 21 000 v/day. Car speeds (15 minute averages) are higher than 85 kph up to 1 300-1 400 v/h, then decreasing to a maximum flow of 1 700 v/h at around 75 kph just before breakdown. Queue discharges with speeds around 40 kph and volumes of 1 300-1 500 v/h indicating an average critical density in the transition zone around 35 v/km.

![Figure 7](image)

**Figure 7:** Average passenger car speeds versus directional flow in the beginning of a one-lane segment, 15 minutes data on E18 Västerås.

From floating car studies on the same road the overall speed was measured to about 90 kph at a 15-minutes flow of 1 550 v/h (two routes just before oversaturation). For a semi-motorway with posted speed limit 110 kph (E4 Gävle) floating car studies resulted in an overall speed of 100 kph at the corresponding flow of 1 350 v/h (Carlsson, 2014). Typical speed variations over consecutive two and one lane segments are presented in Figure 8, based on floating car studies from the E18 Västerås semi-motorway at a directional flow of 1 560 v/h over the first five km. The total section is about 12 km with mixed speed limits of 90 and 110 kph. The top of the diagram gives locations of the one- and two-lane
segments. Large speed variations are observed between consecutive two-lane and one-lane segments. The overall speed is 89 kph in the segments with speed limit 90 kph with 1 560 v/h and 101 kph in the segment with speed limit 110 kph with 1 160 v/h.

Since 2006 there has been a national trend towards slowly decreasing speeds on the rural roads depending of different speed calming measures, mainly speed cameras, decreased police enforcement margin and increased ticket levels. This trend applies also to the 2+1-roads. The travel speeds presented above have been decreased.

The Swedish Transport Administration has a national program for measuring flows and speeds at randomly chosen spots all over the country (TMS-measurements). Average speeds per hour are calculated (time mean speeds) for about 150 hours per year every 3 to 4 years for trunk roads. All flow and speed data from spots on 2+1-roads during 2009-11 have been analysed. Free flow speeds are estimated from hours with traffic flows below 300 v/h in one lane segments and below 650 v/h in two lanes segments. The estimated free flow speeds for cars (including with trailers) are presented below:

- 2+1 with posted speed 110 kph (generally in the northern parts): 103 kph
- 2+1 with posted speed 100 kph (the normal speed limit): 96-99 kph depending of road type semi-motorway or normal 2+m1
- 2+1 with posted speed 90 kph (roads with higher AADT and close to build up areas): 91,5 kph

As can be observed the differences in free flow speeds between different speed limits are about 6 kph, significant lower than the interval of 10 kph. At high flows the merge from two to one lane act as active bottleneck and there is a certain probability for a capacity breakdown. Thus a 2+1 road with consequent merges from two to one lane imply consequent bottlenecks. Since there is a certain probability for a capacity breakdown at each of these merges, the probability for a breakdown along the road stretch can be assumed to increase with the number of merges. This would indicate longer sections and less transitions to improve capacity and level-of-service. It is, though obviously, difficult to estimate breakdown probabilities from real world measurements. It have been discussed if closing the overtaking lane at high flows would decrease the probability for breakdown and increase the capacity. A special attempt to improve the traffic conditions on was conducted on E4 Gävle at holidays with heavy peak traffic. This section with a number of consecutive one and two lane segments is such a bottleneck surrounded by higher capacity sections. The overtaking lanes were closed by the police mainly to improve traffic behaviour and safety at peak week-ends but also to improve level-of-service.
Some field studies were performed to assess level-of-service effects. In the south end there is a transition from two lanes on a motorway into one lane on the first segment. In the north there is an entry lane from a connecting main road to E4 and these two lanes are merged into one lane. The southbound traffic is oversaturated in this bottleneck with a breakdown at the first peak of about 1300-1400 v/h. But in the northbound direction the traffic flows are lower than expected and the capacity has never been exceeded during the peak period. It seems that some drivers have taken an alternative route (which is possible and just a little longer) and therefore the traffic performance has been good on the actual road. One can say that the closed overtaking lanes had an indirect effect.

In another peak holiday the overtaking lanes were not closed and these days the traffic flows were as expected. In the southbound direction the same scenario could be observed with a breakdown at the first peak of 1300-1400 v/h. In the northbound direction the first peak of 1450 v/h could be performed without a breakdown, but after further 30 minutes there is oversaturation with a breakdown. But the first traffic peak has not been able to pass the total length without disturbances. At the exit the flow has decreased to about 1000 v/h which means that there have been oversaturation. In this case (during 30 minutes) closed overtaking lanes should have been successful.

The conclusion is that if it should be any improvements with closed overtaking lanes one had to avoid breakdowns in the first bottleneck. Perhaps this can be managed with a temporary lower speed limit or better merging conditions. An obvious problem with longer sections from a capacity viewpoint is slow moving vehicles.

6 Effects of segment lengths, truck shares and speed variations

The present recommendations on length of one and two lane segments (see Table 2) are based on a number of simulations with the Rural Road Traffic Simulator (RuTSim ver. 200703; Tapani 2005) using a feeding one lane segment varying from 2000 to 11000 m with an adjacent overtaking lane with lengths between 800 and 2000 m creating overtaking lane percentages between 15 and 40 (Strömberg, 2010). Assumed peak flows comprise of 90% private cars, 4% trucks without trailer, 2% buses and 4% trucks with trailers. The peak hour distribution is assumed to be 1% of the AADT and the directional distribution is assumed to be 55/45 up to 300 v/h, 60/40 up to 800 v/h and 65/35 over 800 v/h for peak periods. The free flow speed model was calibrated to correspond with the 2+1 (15% passing lane), 100 kph a sight class 2 level. The most important part is not the absolute values but the relative proportion of the different options. Figure 9 shows results for 20% passing lane at 9 m wide 2+1 as average car speed versus traffic flow for the alternative overtaking lengths. The alternative giving the highest average speed is judged to be the best one. Differences are often quite small.
VTI have performed a number of studies on overtaking lane percentages and flow effects. Given a specific flow and distribution of desired speeds the travel speed increase with increasing length of the one lane segment, see example in Figure 10. The analytical calculation method presented in Carlsson et al. (2013) and Wiklund et al. (2015) can be used to estimate “possible” length for a one lane segment given a specific flow and desired speed distribution.

The two lane segment is used to dissolve the platoons arising during the preceding one lane segment. Example of estimations of minimum lengths of the two lane segments for different combinations of flow and one lane segment length is presented in Table 3.

Figure 9: Speed-flow relationship for 20 % passing lane at 9 m wide 2+1.

Figure 10: Simulated travel speeds over a 1, 2, 4, and 8 km long one lane segment given a normal distributed desired speed with mean value of 100 kph and standard deviation of 15 kph.
Table 3: Estimated minimum length (m) of a two lane segment given different flow levels and length of the preceding one lane segment (Carlsson et al., 2013).

<table>
<thead>
<tr>
<th>Flow (v/h)</th>
<th>One lane segment length (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>350</td>
</tr>
<tr>
<td>40</td>
<td>350</td>
</tr>
<tr>
<td>80</td>
<td>350</td>
</tr>
<tr>
<td>160</td>
<td>350</td>
</tr>
<tr>
<td>320</td>
<td>490</td>
</tr>
</tbody>
</table>

Bergqvist and Runn (2014) presents further investigations of lengths of one and two lane segments. Figure 11 is based on the simulation results presented in Bergqvist and Runn (2014) and show the delay for three different two lane segment length given the same share of two lane segment of the total road length. The figure shows that too short or too long two lane segments might give longer delay. The reason for longer two lane segment lengths to give longer delay is that the increased two lane segment length also to imply longer one lane segments (given the same share of two lane segment length of the total road length).

Figure 11: Example of delay for three different lengths of a the two lane segment given a 20% two lane segment share of the total road length and a heavy vehicle share of 10%.

The traffic simulation results presented in Bergqvist and Runn (2014) match to some extent the recommendations for lengths of two lane segments in the Swedish road design guidelines VGU (Trafikverket, 2014b). The simulation results match quite ok the current recommendations at 20% two lane share while the recommendations for a 30% two lane share deviates (The guidelines recommend much longer two lane segments). In the simulation experiments the lengths of the two lane segments were varied between 900, 1347 and 2693 meters. The VGU recommendation are based on estimations for 800, 1200, 1500 and 2000 meters. Although the VGU recommendations seems to be too long in some cases the minima do not need to be at 1347 meters but could be somewhere between 1347 and 2693 meters depend on the share of two lane segments. More simulations and analysis of different lengths and two lane shares are needed to verify or revise the current recommendations. Differences are small and often of minor importance compared with other effects due to lengths.

The share of heavy vehicles is another important factor to consider when designing 2+1 roads. However, the current speed-flow relationships (Trafikverket, 2014a, Trafikverket, 2014c) only reflects travel speed as a function of flow given a default heavy vehicle share of 12%. Furthermore, the length
recommendations in the Swedish road design guidelines VGU (Trafikverket, 2014b) do not either consider the heavy vehicle share or any detail alignment. Thus, there is a need for further empirical investigations and consequent model enhancement on how the heavy vehicle share effect the travel speed and the recommended lengths of two lane segments. The recommendations on two lane segments also need to be revisited since there are indications that the recommended maximum lengths are too long. Such an investigation could be conducted by a systematic traffic simulation experiment for different combinations of one- and two lane segments, two lane segment shares, traffic flow and heavy vehicle shares. Another issue is the limited knowledge on overtaking tendency on short two lane segments, at which drivers seems to be less willing to overtake since they see the information sign about the merge almost already when the two lane segment starts. Recommendations of maximal length given an accepted maximum average delay could be derived either from the analytical model presented in Carlsson et al. (2013) and Wiklund et al. (2015) or by traffic simulations using for example the Rural Road Traffic Simulator (RuTSim) model (Tapani, 2005).

7 Effects of emergency stops

Traffic delays due to emergency stops and accidents blocking one direction on 2+1-design is by many considered to be a weak point in terms of level-of-service and traffic management. It is very difficult to analyse this issue as data is really hard to find. The only alternative as yet is to use data from the Swedish Transport Administration Incident Data Bank. Data quality is questioned but gives road type and total traffic delay disturbance in vehicle hours estimated from reported incident duration and AADT for each incident according to the TMS traffic count system using the standard formula for deterministic delay.

The comparison is conducted by calculating the part of the total incident delay by road type and the total part of mileage (axle pair km) by road type and then dividing them to get a comparable disturbance index. The result is the 2+1 median barrier road to have the lowest disturbance index 0.7, lower than motorways, see table below. This means on an aggregate level the 2+1 to have less disturbance compared with the traffic mileage than other road types. The explanation could be the substantial cut in severe accidents. The high value for 2+1 median barrier semi-motorways might be explained with the “high” speed limit. Another disturbance problem not covered here is barrier repairs with a frequency around 0.5 per Million axle pair km for wire ropes.

<table>
<thead>
<tr>
<th>Roadtype</th>
<th>Mean 09-14</th>
<th>Mean per year 09-14</th>
<th>Mean per year 09-14</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>km</td>
<td>Mapkm</td>
<td>Mpart</td>
</tr>
<tr>
<td>motorway</td>
<td>1961</td>
<td>18 096</td>
<td>0,29</td>
</tr>
<tr>
<td>2+1 semi-motorway</td>
<td>373</td>
<td>1 697</td>
<td>0,03</td>
</tr>
<tr>
<td>2+1 norm</td>
<td>2168</td>
<td>7 008</td>
<td>0,11</td>
</tr>
<tr>
<td>2 lane</td>
<td>93786</td>
<td>34 290</td>
<td>0,55</td>
</tr>
<tr>
<td>Total</td>
<td>98497</td>
<td>62 551</td>
<td>1</td>
</tr>
</tbody>
</table>

*Mapkm= Million axlepairkm Delay= in minutes using formula Dpart=part of total delay*

Table 4: Incident data by road type

8 Conclusions and further research needs

Level of service on 2+1 roads depend most of the share of two lane segments and the second most important factor is how the share of two lane segments are divided (few and long section compared to many and short sections). The optimal length of one or two lane segments are of less practical interest since factors as intersections and road grade highly limit where it is suitable to place one- and two lane
segments. Disturbances such as: slow moving vehicles and tractors; emergency stops and accidents; and road maintenance and road works; are probably more important than the peak hour conditions. It might be possible to improve transition design, traffic rules, control mode and behaviour to enhance capacity.

The main conclusions from the simulation experiments on the impact of overtaking length on travel times due to traffic volumes and truck ratio are some 1500 m to be a reasonable target and the impact on level-of-service within 1000 to 3000 m to be rather small at normal traffic volumes. The positive effect of an increase from 20 to 30 overtaking lane percentage is estimated to be up to 1.5 sec/km and vehicle. The study of the sensibility to emergency stops due to incidents and accidents for 2+1 roads compared with other standard cross-sections show that 2+1’s do not to create more emergency delays than other cross-sections compared with total mileage travelled is surprising for the general opinion.

The full scale test to close overtaking lanes during heavy peak traffic flows with capacity break downs indicate that capacity in a scientific interpretation have not been impacted positively. However, further research and empirical investigations are needed.

The new speed limit system and review for 2+1:s with the objective to change speed limits from 90 and 110 to 100 kph resulted in car speed impacts around 2-3 kph for means and 85 percentiles. The policy not to accept two lanes roads over 80 kph means mainly superior level-of-service for 2+1-roads with 100 kph.

References


