WEATHER AND TRAFFIC CONTROLLED VARIABLE SPEED LIMITS IN SWEDEN

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Summary
Variable speed limits have been implemented in Sweden at 19 sites throughout the country of which 9 are weather and/or traffic actuated. This paper illustrates the effects for two of the road links, the weather controlled interurban motorway E6 in Halland in Western Sweden and the traffic controlled urban motorway E6 South of Gothenburg. The Halland study mainly shows very positive effects on car drivers’ speed behaviour in severe weather conditions but also that automatic control is needed. The study in Gothenburg shows that harmonisation of speeds and delay in formation and queues also can be achieved in an urban low-speed environment.

Background
The Swedish Road Administration (SRA) initiated an experimental work during 2004-07 aiming at implementing variable speed limits (VSL) on motorways, rural highways and at intersections as part of the VIKING programme. The speed limits are based on weather, traffic conditions and the presence of secondary traffic. The effects for the six intersections were reported at the 13th ITS World Conference in London last year. In this paper the results of the weather and traffic controlled motorways are reported.

The overall problem, which leads to the experimental work with VSL, is the very poor observance of speed limits in Sweden, which has a large negative impact on traffic safety. A series of situations have been identified and test sites chosen. These are:

- Intersections with/without bus stops (vehicle actuated)
- Links with dense traffic and sudden queue build-up (traffic actuated)
- Bad weather- or road conditions (weather actuated)
- Vulnerable road users (close to schools, etc) (user actuated)

Some of the road links are located in urban areas, most intersection sites are on rural highways, while the remaining sites are found in small villages or in a rural environment. Two sites are located on bridges.

Description of test sites
There are widespread knowledge from weather controlled two-lane roads in Finland and also from motorways in mountainous regions. In Sweden tests have made on a motorway in the south-western part of the country along the coast-line, and also on a 2+1 road in Blekinge in the south-eastern part of the country. Results from the Halland site are presented below.

There is also extensive knowledge of MCS-controlled motorways including VSL from various parts of Europe. All these are in a high-speed environment with a basic speed in normal conditions of 110 km/h or more. In Sweden tests have been made on two urban motorway links close to Gothenburg with only 90 km/h and 70 km/h as the basic speed in good conditions. This test gives additional knowledge of
the benefits of VSL also in a low-speed environment. Results from the 90 km/h link passing Mölndal south of Gothenburg will be reported below.

**Halland – weather control**

E6 Halland is an example of a weather controlled motorway. The Halland motorway is situated in the Southwestern part of Sweden. The test period runs from Spring 2005 to End 2007. The total length is 55 km. The test link is divided into eight sub links, which can be given individual speed limits.

The speed limits are manually controlled by the Traffic Information Centre (TIC) of the Swedish Road Administration in Gothenburg. At the introduction of the variable speed limit system in July 2005, the fixed speed limit was raised from 110 km/h to 120 km/h. When adverse weather conditions are detected, the speed limits can be decreased in steps of 10 km/h or 20 km/h. The lowest possible speed limit is 60 km/h.

Traffic flow on the motorway (E6) is about 20 000 vehicles per day, of which about 20% is heavy traffic. The speed limits are controlled according to the expected friction coefficient on the road. If the friction is expected to be 0.4 (moderate rain, light snowfall) the speed limit will be set to 110 km/h, friction 0.3 (heavy rain, moderate snowfall) results in 100 km/h, friction 0.2 (very heavy rain, heavy ice formation) results in 80 km/h and the extremely low friction 0.1 (cloudburst, very heavy ice formation) results in 60 km/h. The expected friction coefficient is calculated based on temperature, moisture, wind speed and wind direction.

![E6 Mölndal and Halland, after implementation of variable speed limits](image)

**Mölndal – traffic control**

E6 through Mölndal is an example of application of VSL on an urban motorway with low posted speed limit. E6 Mölndal, which is situated on the Southern border of Gothenburg has 90 km/h as posted speed limit in normal free-flow conditions. The original motorway had two lanes in each direction and a 90 km/h speed limit. Additional lanes were constructed in December 2002 by repainting and narrowing the lanes (3.25 m). At the same time, the posted speed limit was reduced to 70 km/h day and night. Recommended variable speed limits (without red ring) were implemented two years later (November 2004). In February 2006, the recommended speed have been substituted with controlled speed limits (with red ring). It was part of the project also to identify differences between recommended and controlled speed limits.

The speed limit is reduced in steps from 90 km/h to 70-50-30 km/h in dense traffic. The traffic flow on the motorway (E6) is about 80 000 vehicles per day. When dense traffic is detected (ca 950 v/h and lane) the speed limit is reduced to 70 km/h to prevent the occurrence of sudden break-down of capacity. When risk of queue is detected (v<35 km/h and 20% occupancy) the normal incident detection function for MCS is used for control. When queue formation is detected (v<15 km/h) the speed limit is further reduced to 30 km/h.
Car drivers’ experiences

Halland – weather control

The result from the attitude study concerning VSL on the E6 in Halland shows that the variable signs are easy to detect, see and read according to the majority of the car drivers. The variable signs are experienced as better than the earlier static metal signs. In total, 90% find the system good and 50% is of the opinion that it is even very good. The most common comment on why it is considered good is that it leads to a better traffic rhythm.

Many drivers think that their driving behaviour is improved to certain extent when they pass an illuminated VSL sign. Most drivers (80%) answer that they have been more attentive to the condition of the road surface. Many (around 70%), also state that their behaviour has been improved when it comes to be more concentrated on the driving manoeuvring when they have passed an illuminated sign, to maintain a longer distance to the vehicle ahead, and to be more attentive on other vehicles and also be more restrictive in overtaking other cars.

Mölndal – traffic control

Almost half of the drivers state that they have been more attentive on other vehicles since the VSL was introduced. Around a third answer that they not overtake as often as before and that they keep a longer distance to the vehicle in front. Half of the drivers consider the risk of being hit from behind will be reduced. Twice as many state that the uneven traffic rhythm, the amount of stop-and-go-traffic, and the queue lengths are decreasing compared to those with the opposite opinion. Two out of three think that the system with variable speed limits are good or very good. The most prominent reasons are that it gives good information about the traffic situation and what you can expect further on, i.e. it helps you to be more attentive to the changing traffic conditions.

Speed changes

Halland – weather control

Speed measurements have been conducted after implementing VSL on the E6 in Halland in the period February to June 2006. A major problem is to compare speeds with the same weather conditions in the pre and post study. The registrations from the road weather stations (VViS) have been used as a proxy to define the same conditions as well before as after implementation of VSL. After implementation of VSL, the fixed speed in dry conditions was raised to 120 km/h. In bad weather conditions the speed limit can be reduced to 110 km/h down to 60 km/h. Figure 1 shows the resulting average speeds (18% trucks) in different weather conditions for one of the analysed detector points, Hökaslätt, in the Northern direction.

**Figure 1**  E6 Halland, average speeds after implementation of VSL

![Figure 1](image-url)
The speed measurements from the pre-study reveal an extremely bad adaptation of speeds to severe weather conditions. The resulting speed in very slippery conditions is only 9 km/h lower than in dry weather conditions. These results indicate that the risk in very slippery conditions will be over ten times higher than in normal conditions. It seems therefore very adequate to assist the drivers in assessing the suitable speed in bad driving conditions.

The resulting speed measurement after implementation of VSL show that the drivers do not speed up very much when the speed limit has been raised from 110 km/h to 120 km/h. The difference is surprisingly small, only 1 km/h. It seems that the majority of the drivers are satisfied with the current speed limit of 110 km/h that is used on most of the motorways in Sweden. Looking closer at the results, we find that the passenger car drivers in the overtaking lane increase their speed in good conditions from 117 km/h to 124 km/h. But these driver only count for 30% of the traffic volume.

The speed measurements from E6 Halland show small adaptations in snowy conditions. When the speed limit is reduced down to 80 and 60 km/h, however, the drivers seem to understand that the weather conditions are really severe. In this case, the average speeds are 27 km/h lower than in good conditions and also 14 km/h lower than the speeds before implementation of VSL.

Mölndal – traffic control

Speed changes depend on the criteria that are used for the detection, how the system is interpreted by the drivers and how the speeds are enforced. After implementation of VSL the normal posted speed was raised, which has resulted in 7 km/h higher speeds in free-flow conditions. In dense traffic, almost all of the speed increase emanating from the increase in the posted speed limit remains.

Table 1  
E6 Mölndal, average speeds after implementation of VSL

<table>
<thead>
<tr>
<th>Northern Direction</th>
<th>Post-study VSL speed</th>
<th>Difference compared to pre-study</th>
<th>Post-study Share of traffic</th>
<th>Difference compared to pre-study</th>
</tr>
</thead>
<tbody>
<tr>
<td>90 km/h, free flow</td>
<td>86,1</td>
<td>+7,0</td>
<td>72,4%</td>
<td>+1,1%</td>
</tr>
<tr>
<td>70 km/h, dense traffic</td>
<td>72,1</td>
<td>+6,1</td>
<td>27,5%</td>
<td>+2,8%</td>
</tr>
<tr>
<td>50 km/h, risk of queue</td>
<td>71,2</td>
<td>+40,2</td>
<td>0,1%</td>
<td>-2,7%</td>
</tr>
<tr>
<td>30 km/h, queue formation</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-1,2%</td>
</tr>
</tbody>
</table>

When risk of queue is detected and 50 km/h is switched on, the average speed has increased with as much as 40 km/h. This result indicates a substantial improvement in the driving behaviour in dense traffic conditions. The traffic have been harmonised as desired and the gaps between the vehicles have been smoother. Sudden stops have probably been reduced to a great extent. Queue formations when 30 km/h should have been switched on have not occurred at all during the measured period.

Safety benefits

Halland – weather control

The results on E6 in Halland are encouraging and show that VSL are working as intended and can stimulate drivers to slow down in severe weather conditions. It seems to be intuitive for drivers to reduce speed to a certain amount, in this case 10 km/h, in bad weather conditions. But it seems also to be hard to really understand how much you should reduce your speed when the conditions are extremely bad. The conclusion according to Figure 1 seems to be that VSL has a minor role in wet and snowy conditions. The major role of VSL is when the weather conditions are really severe. In this case, speed reductions and safety benefits can be significant.

An important observation was also that the share of traffic with 60 och 80 km/h is lower than expected after implementation of VSL. The probable cause is that the lower speed limits have not been fully used. The same experience was acquired in Finland when weather control experiments started in the 90’s with manual control from the Traffic Control Centre. The probable result in Halland is therefore
that 100-110 km/h has been shown also in situations where the most suitable speed limit should be 60-
80 km/h.

Theoretical calculations indicate a 10% drop in accident costs if the system was adapted to the weather
situation according to the weather situation. With the actual delay in signing that has occurred there
seems to be only marginal safety benefits. Looking at the accident record there has been a reduction of
the number of injury accidents from 34 to 29. A confusing fact is however that there has been an
increase during the winter with 40%, when it was assumed that VSL would be most beneficial.

Mölndal – traffic control
The accident record is very beneficial after implementation of VSL on the E6 in Mölndal. Injury
accidents has been reduced with 20% with recommended variable speed limits and with 40% with
controlled variable speed limits. The number of accidents is however too small to draw any statistical
conclusions. We need at least two more years to indicate how significant this result is. The fear for
more accidents because of the increase of the speed limit during free flow conditions from 70 km/h to
90 km/h seems however to have been exaggerated.

Conclusions
Halland – weather control
• Variable speed limits influence vehicle speeds substantially during severe or very severe road
surface conditions. The drivers are stimulated to reduce speed with a further 13-14 km/h
thanks to VSL.
• The respect for the normal speed limit (120 km/h) has been substantially greater after
implementation of VSL compared to other motorways. Much fewer drives more than 10 km/h
over the speed limit.
• The investment is probably not socio-economically profitable with the present design, costs
and operation. In accordance with Finnish experiences, steps should be taken towards
increased efficiency and automation. If this succeeds, weather control on motorways can be
profitable.

Mölndal – traffic control
• Acceptance for VSL is very high. Accessibility has been improved in free-flow and dense
traffic and average speeds have been increased. Situations with queues, that lead to big delays,
have been substantially decreased.
• Accidents seem to have been decreased despite the higher posted speed limit in free-flow
conditions.
• Implementation of VSL seems to be profitable also on urban motorways with a posted speed
limit of 90 km/h.

The preliminary results show that severe weather conditions should be the focus of weather-controlled
variable speed limits. It is however extremely complicated to detect such conditions. Research and
 calibration of the relationship between friction and weather conditions in the VSL algorithms should
therefore continue.

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References
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