# TRAFFIC CALMING AT MOBILE ROADWORK ZONES: USE OF VEHICLE-MOUNTED RADAR TO EVALUATE THE EFFECT OF VARIABLE MESSAGE SIGNS

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**ABSTRACT/RÉSUMÉ: TRAFFIC CALMING AT MOBILE ROADWORK ZONES: USE OF VEHICLE-MOUNTED RADAR TO EVALUATE THE EFFECT OF VARIABLE MESSAGE SIGNS**

Some of the worst accidents at roadwork zones in Sweden involve caravans of road marking vehicles. High traffic speeds past roadworks is recognised as a frequent causal factor. This study was aimed at evaluating the traffic calming effect of a set of Variable Message Signs (VMS), mounted on a slow-moving caravan of road marking vehicles. The VMS displayed the maximum recommended speed throughout the zone. The results were evaluated by means of new small portable radar equipment that surveyed the speed of vehicles both passing and meeting the caravan.

The case results showed that without activating the VMS, both the average and top speeds were very high, thereby entailing an unacceptable risk. However, when the VMS was activated, the average speed was reduced by 22 km/h on wide roads. Similarly, the mean speed of the ten fastest vehicles was reduced by 16 km/h. Finally, the percentage of vehicles driving at extremely high/hazardous speeds (> 70 km/h) dropped from 62% to 12%, which is a relative reduction of 81%. As a result, Swedish legislation is being reviewed with the intention to legalise the use of this type of VMS on moving road work vehicles.

## 1. INTRODUCTION

Road deaths and severe traffic injuries are a major public health problem worldwide. Some 450 people are killed in Sweden every year and thousands are injured for life as a result of accidents on streets and roads. The decision by the Swedish Parliament to adopt “Vision Zero” implies that ultimately no one will be killed or seriously injured on roads in Sweden. The first of the three designated problem areas addressed by ”Vision Zero” concerns better speed adaptation, not least of all past roadworks. Several serious accidents have occurred at roadwork sites in Sweden in recent years.

Today there are a great many road workers who feel insecure and nervous while on the job. Several Swedish studies based on an analysis of questionnaires completed by road workers revealed that they feel uneasy and unsafe in the course of their work and that this is due to traffic-related factors, in particular traffic speeds past the work site rather than other work-related factors [1]. Several international analyses of accident data have shown that high speeds account for a large percentage of all accidents at roadwork sites [2]. At the same time, other studies have shown that road stretches with roadworks in progress are more exposed to accidents than stretches without [3], something that many consider to be unnecessary. In other words, the anxiety felt by road workers is totally legitimate.

2007 has been designated by the Swedish Road Administration as ”Road Safety Year”. A wide range of activities have been planned to address the subject of high traffic speeds, including those at roadworks. The working environment at roadwork sites has been repeatedly pointed out within the industry as an area where there is a major need for improvement.

Roadwork sites cause traffic situations that are unusual and unexpected by many drivers. Inconsistent and sometimes inappropriate traffic management arrangements can often be a source of confusion, causing drivers to make mistakes. A large percentage of motorists drive past roadworks at speeds that are too high under the circumstances, and often far above the speed limit [4]. Sometimes drivers are unaware of their high speeds before encountering a completely unexpected situation (like a roadworks site), resulting in hasty and abrupt behaviour. At the same time, many consider themselves to be careful drivers, and trust in their ability to drive at a proper speed and make the right decisions [5,6].

Swedish reports in the early 2000's indicated that road workers were becoming more and more uneasy. Even if no extensive monitoring of speeds at roadwork sites had been carried out at that time (and still hasn't) it is thought that the growing anxiety could be related to an increasingly aggressive traffic rhythm [7,8].

From an international perspective, safety studies at roadwork sites in many countries unfortunately only cite previous studies. Further, development projects are often relegated to the status of "working material" or ”practical experience" – and never published as scientific reports. This applies not least of all to the implementation of safety-enhancing new technology, such as changeable signs and information systems that can be adapted to the prevalent situation. There are few comprehensive descriptions covering roadwork sites, driving speeds and road safety. To sum up, very little experience is shared and exchanged between countries.

### 1.1. The "Safer Road Works" project and mobile roadworks

As mentioned in the foregoing, serious accidents occur in roadwork zones every year in Sweden. Some of the worst of these have involved caravans of road marking vehicles [9-12]. High traffic speeds past roadworks is recognised as a frequent causal factor. Many studies have been conducted on the effect of traffic calming measures in general [13-27]. Although some of these have examined stationary roadwork zones, virtually none have studied intermittent (short periods of "stationary" works in stop-and-go cycles) or mobile roadwork zones, simply because such studies are extremely complicated in practice.

The challenge of examining traffic speeds past roadwork vehicles was addressed in a study aimed at evaluating the traffic calming effect of a set of Variable Message Signs (VMS), mounted on a slow-moving caravan of road marking vehicles. During the Swedish Road Administration's ”Hunting for Ideas" campaign some proposals recommended mounting a sign displaying the threshold speed on the roadwork vehicles.

The ”Hunting for Ideas" campaign, run in 2002-2004 by the Swedish Road Administration, was arranged to collect ideas from employees on how to improve safety at roadworks. This resulted in over 130 proposals being submitted, the best of which were amalgamated into a few studies within the project designated "Safer Road Works" [25]. This project was financed by the Swedish Road Administration, and carried out by Vägverket Produktion in cooperation with the largest Swedish trade union organisations (SACO, SEKO and TCO). Furthermore, the project had a steering group comprised of key persons and a reference group consisting of road safety experts.

The VMS displayed the maximum recommended speed throughout the zone. The results were evaluated by means of new small portable radar equipment that surveyed the speed of vehicles both passing and meeting the caravan. The aim of this study was to evaluate the effect of a sign mounted on road marking vehicles to display the recommended speed.

## 2. METHOD

### 2.1. Field trial implementation

For the field trial, road markings were carried out as normal. On roads other than motorways in Sweden, a road marking caravan normally comprises three vehicles: a forerunner vehicle facing on-coming traffic, a road marking vehicle in the middle of the caravan and a vehicle at the rear equipped with TMA (Truck Mounted crash impact Attenuator). For obvious reasons, there is no forerunner vehicle in the caravan on motorways or other roads without oncoming traffic. On the other hand, an additional vehicle is required at the very rear of the caravan on motorways in order to direct traffic to one side past the roadwork site.

All the vehicles in the caravan were equipped with two signs displaying the recommended speed, as shown in Tables 1 and 2. To measure the effect of these LED (digital) signs, the vehicle caravan simulated road marking operations. The field trial was reproduced on a few Swedish highways where the VMS was set at “30 km/h”. Reference speeds were also obtained through test runs where the VMS was switched off (blacked out). All traffic speed data was calibrated to take into consideration the speed of the caravan vehicles.

**Table 1 -** Sign used during the field trial on roads with oncoming traffic *(not motorways)*. The table shall be read from left to right and indicates the vehicle referred to and the direction of traffic in relation to the vehicle in the caravan.

| **Direction of traffic** | **Vehicle in the caravan** | | |
| --- | --- | --- | --- |
| | **Forerunner vehicle** | **Road marking vehicle** | **Vehicle with a TMA** |
| On-coming | 50 | 30 | /// |
| Passing | /// | 30 | 50 |

**Table 2 -** Sign used during the field trial on roads without oncoming traffic *(motorways)*. The table shall be read from left to right and indicates the vehicle referred to and the direction of traffic in relation to the vehicle in the caravan.

| **Direction of traffic** | **Vehicle in the caravan** | | | |
| --- | --- | --- | --- | --- |
| | **Vehicle with a change lane sign** | **Vehicle with a TMA** | **Middle vehicle with a TMA** | **Road marking vehicle** |
| Passing | ------ | 50 | 30 | 30 |

Field trials both with and without LED signs were conducted on five different Swedish roads located 100-150 km west-north-west of Stockholm: E18 (Köping-Arboga), E20 (Kvicksund-Arboga), Road 53 (E18-Kvicksund), Road 67 (Västerås-Nääs-Sala, both in daylight and darkness) and Road 70 (Sala-Avesta). All the roads, except for the E18 European Highway between Köping and Arboga, had one single lane in each direction. The lane width on these was approximately 3.5 - 4 metres in each direction, with a shoulder width that varied from between 0.5 and 3 metres." Radar equipment type SR3+ was used to survey such variables as speed, type of vehicle, length, time, etc for those vehicles meeting or passing the caravan. All speed data was calibrated to take the caravan mounted radars own speed (plus or minus, as appropriate) into account.

2.2. Statistical analysis

In connection with this particular evaluation study, a multivariate statistical analysis of the data was conducted to find out if these signs had any speed calming effect. Three key response variables were identified: the median speed, the mean speed of the ten fastest vehicles and the percentage of cars driving at a dangerous speed (> 70 km/h). Speeds were measured adjacent to the different vehicles in the caravan and the following explanatory categories were determined: road identity; road width in two classes (< 10m & > 10m); status (with or without an LED sign); direction (meeting or passing vehicle); position (first, middle & last). The position was coded in relation to the vehicles passing or meeting. In other words, the "first" position indicated an oncoming vehicle meeting the front vehicle in the caravan, and the rear vehicle in the caravan in the case of passing vehicles.

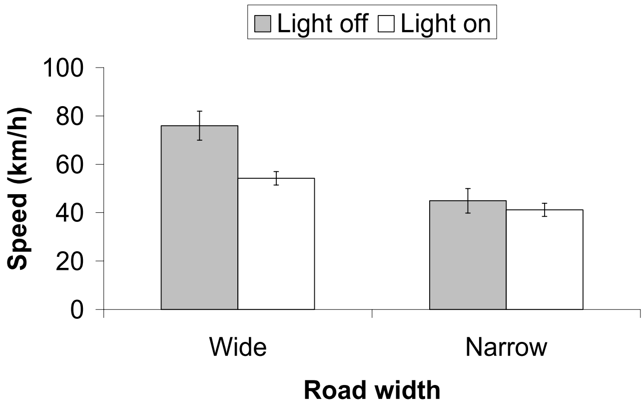



Figure 1 - Median speed of vehicles passing and meeting a caravan of marking vehicles in relation to road width and the presence of activated signs (backtransformed mean ±S.E.). The roads are classified as narrow <10 m and wide >10 m.

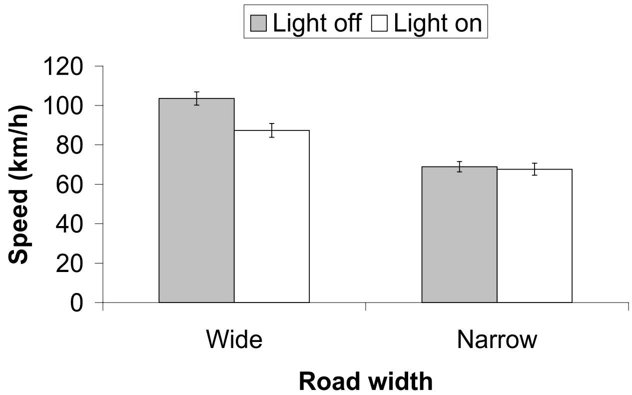



Figure 2 - The mean speed of the 10 fastest vehicles passing and meeting caravans of marking vehicles in relation to road width and the presence of activated signs (backtransformed mean ±SE). The roads are classified as narrow <10 m and wide >10 m.

Based on these categories, responses were evaluated using a linear mixed effects model with "position", "direction" and "status" gathered under "road" in the S-Plus statistics program. All non-significant interaction terms ($p>0.05$) were subsequently excluded from the full model for the sake of simplification. In the final model, residuals were controlled but were well-behaved in all cases.

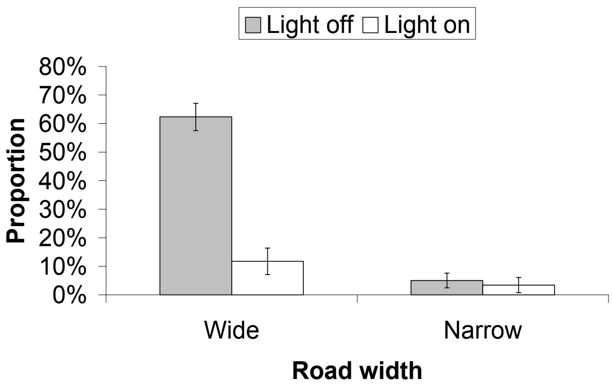



Figure 3 - The percentage of vehicles passing and meeting a caravan of road marking vehicles that are driving dangerously fast (> 70 km/h) in relation to road width and the presence of activated signs (backtransformed mean±SE). The roads are classified as narrow <10 m and wide >10 m.

Although there were a large number of significant interactive effects for each response variable, any effect that did not include “status” and “road width” was ignored, as it was considered to be irrelevant to the question at hand. For each response variable, there was a significant interactive effect of “status” and “road width” ($p<0.05$) but no significantly

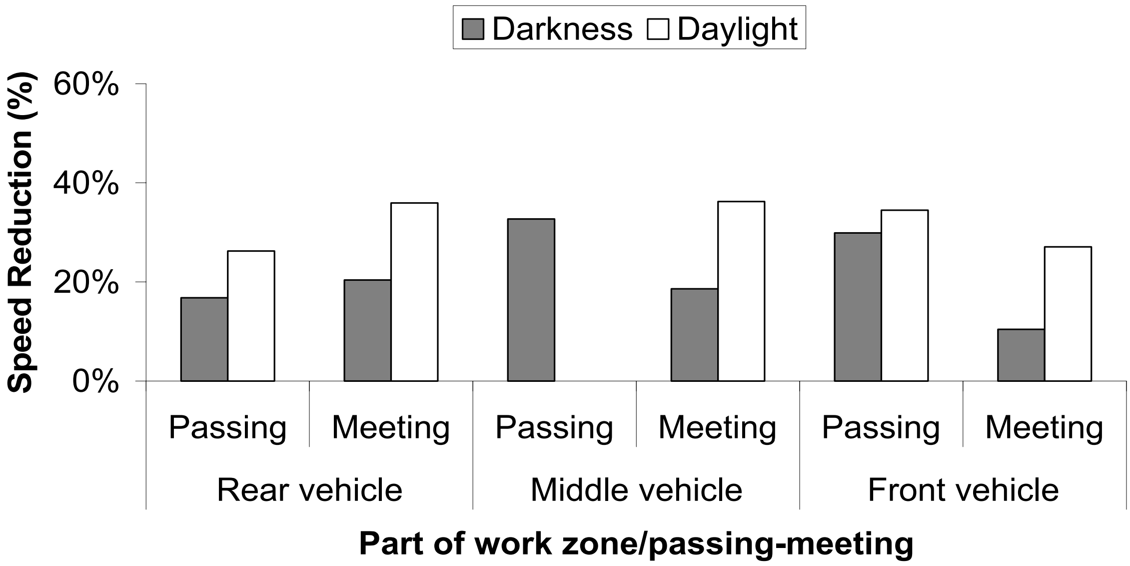



Figure 4 - Caravan of road marking vehicles equipped with signs in both darkness and daylight on Road 67 (Västerås-Sala). Comparation during darkness and daylight on Road 67. Observe that no data was collected for vehicles passing the middle vehicle in daylight.

higher order interaction for a combination of these variables. Thus, it was sufficient to focus on these two variables, making the interpretation rather easy and straightforward.

## 3. RESULTS

The presence of LED signs reduced the median speed by 22 km/h on wide roads but only by 4 km/h on narrow roads (Figure 1). Similarly, the mean speed of the 10 fastest vehicles was reduced by 16 km/h on wide roads but only by 1 km/h on narrow roads (Figure 2). Finally, the percentage of vehicles driving faster than 70 km/h was reduced by 81% on wide roads but only by 32% on narrow roads (Figure 3). As a consequence, only 3% of the vehicles on narrow roads and 12% on wide roads drove dangerously fast where there were LED signs, while the corresponding figures without these signs were 5% and 62% respectively.

A comparison of the effect of the signs on speed reduction during hours of darkness and daylight on Road 67 indicates that the degree of lightness is a factor that has a significant influence on the speed calming effect of the LED signs (Figure 4): the speed reduction is much more obvious in daylight than in darkness, which is primarily due to generally lower driving speeds at night, with or without signs.

The results from the only motorway studied during the field trial – the E18 European Highway between Köping and Arboga – showed a clear reduction in the average speed when the signs were activated: 14 km/h (TMA vehicle), 24 km/h (middle vehicle) and 21 km/h (road marking vehicle). The percentage of vehicles driving faster than 75 km/h past the road marking vehicle was reduced from 66% where there was no sign (maximum recorded speed was 133 km/h) to below 1% where there was a sign (maximum recorded speed was 109 km/h).

These results indicate that the effect of the signs is greater by the road marking vehicle (middle vehicle) and at the end of the worksite (whether this be the TMA vehicle or forerunner vehicle, depending on whether traffic is meeting or passing the caravan) than at the beginning of the work site (Figure 5-6).

At all the field trials, and in the case of both meeting and passing traffic, the speed reduction was higher, expressed as a percentage, by the road marking vehicle than by the vehicle with TMA protection.

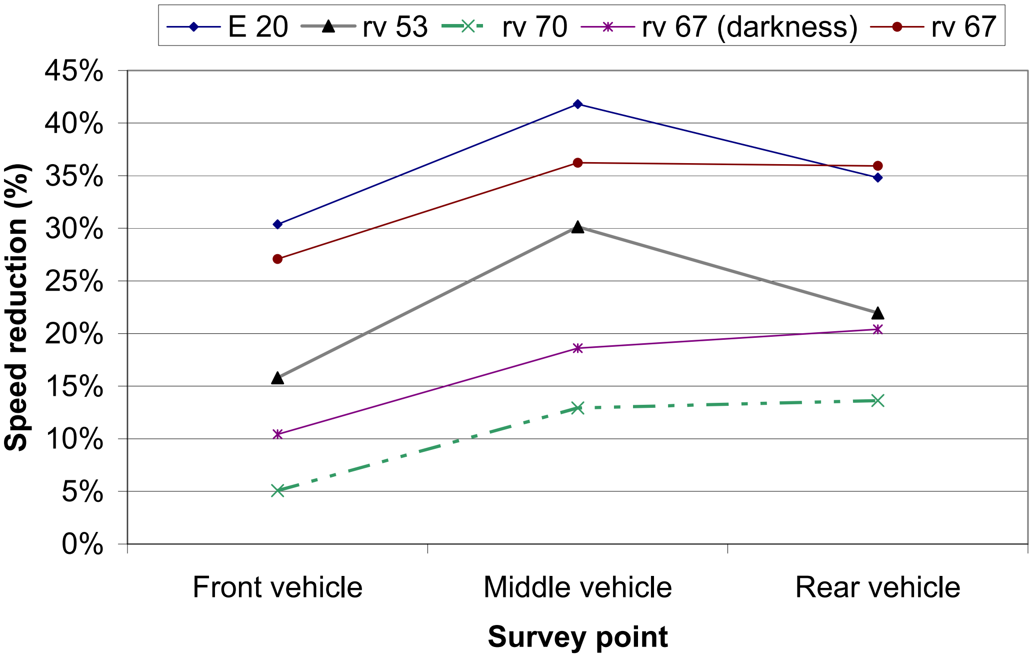
## 4. DISCUSSION

### 4.1. Interpretation of the results

The evaluation of the vehicle-mounted digital sign method showed several significant traffic calming effects. A substantially lower average traffic speed past the site was found where there were signs displaying the recommended speed. The difference, depending on whether or not there was a sign, was particularly obvious in the case of those vehicles that drove the fastest. Accident records in connection with road marking and other accident analyses have shown that vehicles that drive the fastest are heavily overrepresented in accident statistics.

Furthermore, road workers were very positive to this method, saying that they felt safer and were under the impression that traffic had slowed down (in the personal view of Gunnar Larsson, head of the road marking caravan). The road markings crew found the signs easy to use and described the time it took to handle them as negligible. One very positive result was that the greatest speed reductions were by the road marking vehicle, where workers are most vulnerable.

The signs have now been used for a year at many roadwork sites since the field trial. A greater effect was found on roads wider than 10 metres. Based on these study results, it was proposed that an LED sign mounted on vehicles displaying the recommended speed during road marking operations should be used on roads wider than ten metres. Further,



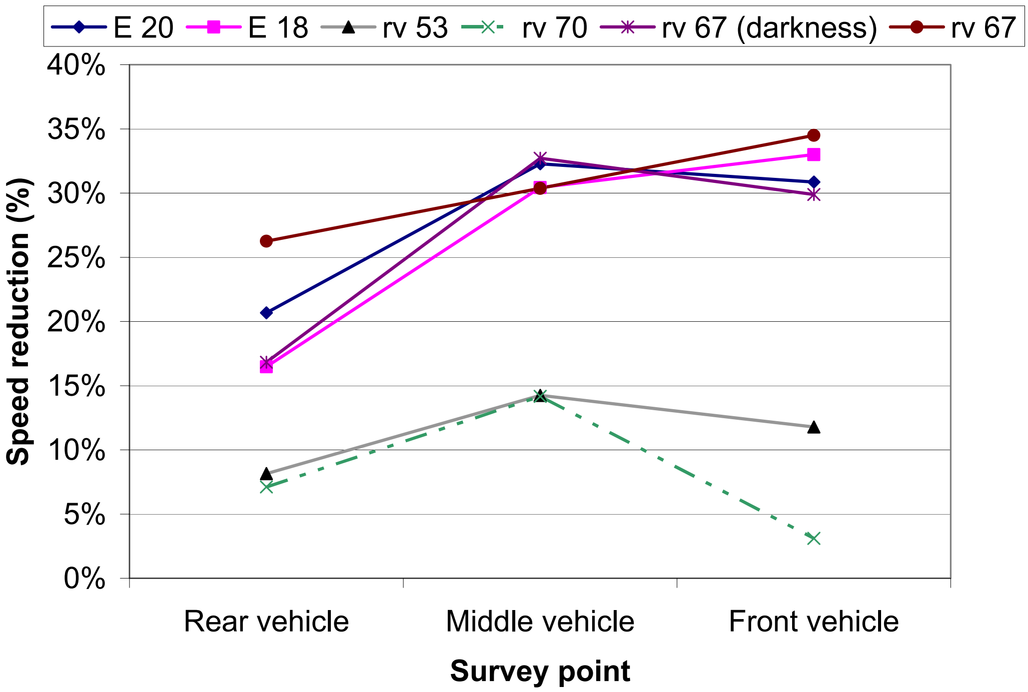




Figure 5-6 - Speed reduction in percent past different vehicles in the road marking caravan. Meeting above (5), and passing below (6).

the results indicate that the speed calming effect depends on the light conditions. A probable explanation could be that drivers generally drive more slowly in darkness and the reduction when the signs are activated is therefore less obvious.

### 4.2. Radar technology for studying traffic past mobile roadworks

As mentioned above, only a few studies have analysed the use of speed calming equipment at stationary roadworks. For practical reasons it is much more complicated to

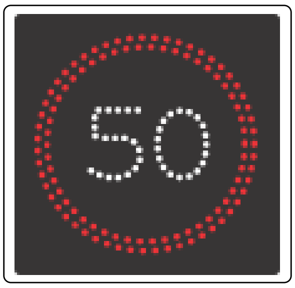



Figure 7 - Example of a VMS. The pixels in the sign can be produced using fibre optics or light emitting diodes. This LED sign was used in the project, for instance, to evaluate the effect of a VMS displaying the recommended speed.

study the effect of traffic calming equipment at short-term, stationary roadworks or even at such mobile worksites as road marking operations. This study shows that relatively new, modest radar equipment, for example of type SR3+, could be used in the future for analyses of traffic passing and meeting moving roadwork vehicles. The new radar-based measurement method can be recommended for use in similar studies, such as in analyses of the effect of various roadwork vehicle markings (flashing lights, symbols, colours, fluorescence, retroreflection, etc).


Figure 8 - LED sign in a sunny wintry landscape with the light from the side. In Sweden normal speed limit signs have been completely replaced by remote-controlled digital signs at a few roadworks. Observe the red border on the sign, which shows that this is more than just a recommendation. No evaluation comparing digital and traditional signs has been conducted as regards driver comprehension and the impact on speed. Some are of the view that it can often be more difficult to see digital signs than normal signs. Works executed by Vägverket Produktion at Västerås-Köping, February 2007.

## 4.3. Choice of speed limit /recommended speed

Speed limits must be realistic, justifiable and changeable. If the speed limit seems unwarranted, there is a greater risk that it will be ignored. Neither should the speed limit be extremely low if traffic is to move smoothly. A good way to achieve a smooth flow of traffic can be to provide information about the worksite well in advance of the speed reduction, and gradually reduce the posted speed limit (70, 50, 30 km/h), as was done in this study.

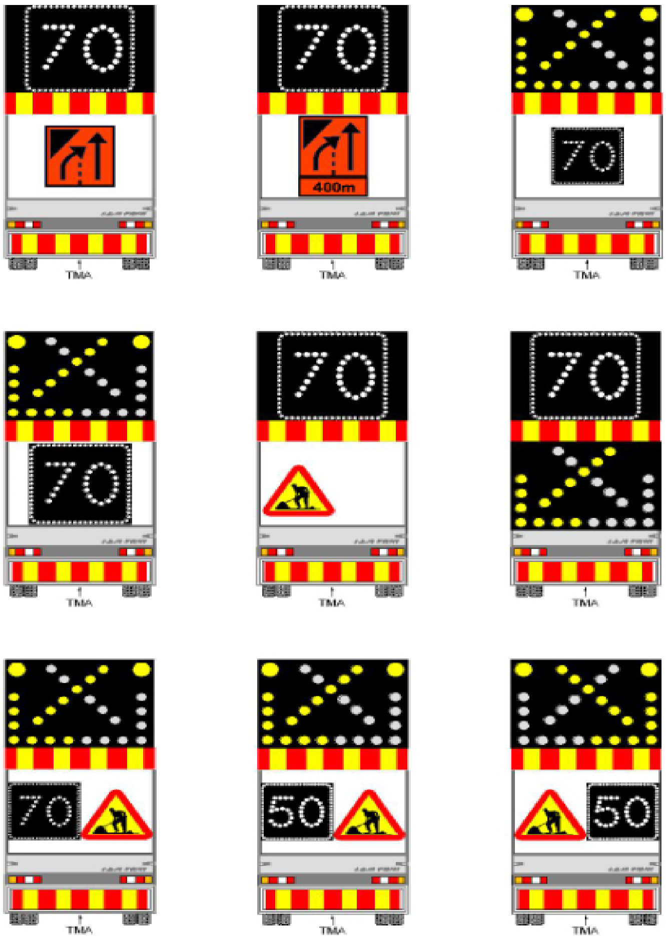



Figure 9 - Digital signs displaying the recommended speed. These are included in a proposal scheduled to be passed in Mars 2007, and currently expected to gain legal force in June 2007. Worthy of note is the lack of a red border around the speed limit figures. A red border had assigned the signs the same status as normal, stationary speed limit signs. Technically it is possible to measure speeds and record speeding offences past moving vehicles, but due to impediments in Swedish legislation, the signs will not be more than a recommendation. An explanatory note will be entered into the Swedish Road Administration's code of statutes. The proposal can be viewed as a result of the findings in this study.

It can be worth mentioning that road marking caravans do not always look the same in different countries, or even within Sweden for that matter. The reason for wanting to limit driving speeds in Sweden past a road marking caravan to the extent desired, is that road marking vehicles are so small and their drivers are so very exposed. It is still not completely sure what actual speed limit should apply for road marking caravans as described in this article.

The Swedish Work Environment Authority [28] has set 30 km/h as the ”maximum actual speed” (note the wording) for vehicles driving past building and civil engineering works where there are unprotected road workers if the lateral distance is less than 2.5 metres. Lateral distance refers to the distance between workers and the edge of the closest traffic lane. In the same publication it is stated that 50 km/h applies where this distance is more than 2.5 metres. 70 km/h applies at works where there are safety protection barriers, provided that these barriers meet the class T2 (SS-EN 1317-1 and 2) specifications. These limits represent the Swedish Work Environment Authority’s interpretation of its own code of statutes for building and civil engineering works (AFS 1999:3) [29]. It is not clear how “unprotected” it considers drivers of road marking vehicles to be.

In Sweden it is becoming increasingly more common to fit road marking equipment on larger vehicles. This might be a way to circumvent the problem and be able to accept higher speeds past road marking works.

## 4.4. New regulations for displaying recommended speeds on moving vehicles

As a result of this study, Swedish legislation is being reviewed with the intention to legalise the use of this type of VMS on moving road work vehicles (Figure 9-10). Although there currently are legal impediments against the use of mobile prohibitory signs for speed limits, digital signs on moving vehicles displaying the recommended speed are included in a proposed amendment to the Swedish Road Sign Ordinance which is expected to gain legal force in June 2007, as a direct result of the findings in the project at hand.


Figure 10 - LED (digital) signs mounted on trucks displaying the recommended speed during road marking operations. Enköping, 50 km northwest of Stockholm, 2005. Observe the white radar equipment (type SR3+) down to the right of the truck.

Technically it is possible to measure speeds and record speeding offences past moving vehicles, but due to impediments in Swedish legislation, the signs will not be more than a recommendation. An explanatory note will be entered into the Swedish Road Administrations code of statues.

### 4.5. Possible problems and suggestions for future initiatives

An attempt was made to discuss any possible obstacles that would interfere with the implementation of these methods. It was found that there could be a problem concerning who assumes the responsibility for the traffic calming equipment. Private companies feel that some of the methods are expensive and should therefore be owned and implemented by the road authorities. The size of the LED (digital) sign mounted on vehicles to display the recommended speed during road marking operations was also a potential problem. In combination with other traffic regulating signs there is not always sufficient space available on the vehicle.

There appears to be extremely little research being conducted within the field of Variable Message Signs at road work zones. In Sweden these are used in the form LED road signs both to display recommended speeds (number only) and signs that correspond to normal speed limit signs with a red border. No studies have been conducted to show if drivers understand the difference between signs with or without a red border, either at the national or international level. In Sweden major effort is being expended on amending the Road Sign Ordinance, including an extensive information campaign in this regard.

Another subject that is being discussed but without any studies being conducted concerns the visibility of digital VMS signs as compared to normal signs (see Figure 7). There already are roadwork sites in Sweden where normal, stationary speed signs have been completely replaced by LED signs, which means it would be desirable if an evaluation of this could be initiated.

## 5. CONCLUSIONS

• A considerably lower average traffic speed past roadworks was found when digital signs were used. The difference in speeds between when signs were and were not (reference) used was particularly noticeable in the case of vehicles that drove the fastest.
• The effect is greater on wider roads and on roads where the average speed of vehicles driving past the site without supplementary signs is high.
• It is proposed that the use of supplementary signs be made mandatory in the future – particularly on roads with an average width of at least 10 metres and where the ordinary speed limit is predominantly at least 70 km.

## 6. CLOSING WORDS

Some of the results have been presented in the Swedish entry to the PIARC PRIZE 2007 for Road Safety.

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