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Towards a European guideline for speed management measures in work zones

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Abstract

Speed management in work zones is important to ensure that the driver safely can navigate the vehicle through the work zone routing. The ASAP project, Appropriate Speed saves All People, was designed to address this issue, with its specific focus on speed management measures and treatments that increase road safety both for the road workers and the road users. The objective was to provide a best practice document that can be applied across Europe with recommendations on how to effectively manage speed through roadwork zones. The guideline provides solutions to help achieving the appropriate speed on different road types and roadworks independently of country. The study showed that most of the speed management measures have some effects on reducing speeds, and even when only minor speed reductions are achieved, these measures may effectively alert drivers to an upcoming roadwork, thereby increasing the safety.

Peer-review under responsibility of Road and Bridge Research Institute (IBDiM)

Keywords: work zone; speed management; road safety; guideline; enforcement; roadwork

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1. Introduction

A work zone entails deviations from normal travel in a discrete road section and may include abrupt deviations from the regular road design. Without proper control of the vehicle, a driver may collide with other vehicles, run off the road, or even enter the restricted areas of the work zone. Vehicle encroachments into these areas can cause injury to the car occupants as well as the road workers, and may also damage work equipment and vehicles.

Speeding is clearly a factor that contributes to traffic accidents within work zones (Li and Bai, 2009; Dissanayake and Akepati, 2009). For this reason, speed management in work zones is important for the safety of both the road user and the road worker. Selection and control of traffic speeds are crucial components for road safety and appropriate speed is needed to ensure that the driver can travel safely through the work zone routing.

It is also important that the road users are presented with consistent and understandable measures, regardless of where they travel within Europe. The Conference of European Directors of Roads (CEDR) has established transnational road research projects regarding work zone safety in the 2012 Safety Programme. Four specific research themes were identified for this call and the ASAP project – Appropriate Speed saves All People – was designed to address the issue of speed management in work zones, with its specific focus on speed reduction measures and treatments in order to increase road safety both for the road workers and the road users. The ASAP project was funded within the CEDR Cross-border Transnational Research Programme 2012: Safety, by the national directors of roads in Belgium/Flanders, Germany, Ireland, Norway, Sweden, and the United Kingdom.

2. Background

The PRAISE project which focused on preventing road accidents and injuries for the safety of employees concluded that the presence of work zones increases accident risk and that working on the roads is one of the most dangerous occupations. Furthermore it stated that improved safety practices can reverse these scenarios (European Transport Safety Council, 2011). General information on work zone crashes shows that the US had 831 fatalities in work zones in 2007. Similar statistics were recorded in the period 2000–2009 in the Netherlands (SWOV, 2010) where an average of 18 fatal crashes (2% of all fatal crashes) occurred at roadworks. During the years 2003–2012, 2 435 severe crashes occurred at various types of roadwork in Sweden (Liljegren, 2014). Of the 2 435 crashes, 1.7% were fatal accidents and 21.3% were accidents with serious injuries.

Statistics show that speeding is a leading contributing factor in traffic crashes and fatalities within work zones. Research conducted by the Kansas University (Dissanayake and Akepati, 2009) showed that speeding contributed in 30% of the fatalities that occurred in the U.S work zones in 2008. According to Federal Highway Administration, speeding was the contributing factor in 23% of all the fatal work zone crashes in 2013 (FHWA, 2015).

There are safety limitations and particular dangerous situations to consider both when deciding on speed limits and when securing speed levels in work zones. The relationship between speed level and crash severity is an important factor for the safety of road users as well as road workers. High speeds impose increased worker injury risks. The higher the impact speed is, the more serious the consequences become, in terms of personal injuries and material damage. A study conducted by the Organisation for Economic Co-operation and Development (OECD) and the European Conference of Ministers of Transport (ECMT) reporting that reductions in average speeds of approximately 5% would result in a reduction of fatalities of about 20% (OECD/EMCT, 2006).

The presence of road workers and their exposure to road traffic represent crucial safety limitations when deciding on the appropriate speed level and temporary speed limits at roadworks. As for any other pedestrian the death risk in case of an accident increases rapidly for workers on foot as the driven speed increases (Kröyer et al., 2014). When deciding on appropriate speed behaviour the expected speed at the time of a collision is of major importance. To find this speed the estimation of the stopping distance is also an important variable since this distance increases exponentially with increased speed (PIARC Road safety manual, 2003). To avoid that traffic vehicles encroach the work area if they leave their trajectory the lateral safety distance between the activity area and traffic is also a key issue when designing a safe work zone. An appropriate safety zone and/or a physical work zone separation indeed help mitigating the risk of collision with workers and the driven speed obviously affects the needed width of the safety zone and the type of physical separation used, as specified for example by the Danish Road Directorate (Vejdirektoratet, 2013). In fact, many national guidelines impose the temporary speed limit as a function of the workers' distance from the traffic flow.

Another essential element for safety at roadwork sites is related to the design of lane shifts and the type of work zone layout. Some guidelines state that additional speed reductions should be implemented where the traffic is crossing

the central reserve, due to the presence of the work zone. The level of reduction partly depends on the length of the median opening and on the number of lane changes.

Migletz et al. (1998) reported that speed compliance in the US work zones is generally higher where the speed limit reduction is lower than 10 mph (16 km/h). They also state that in work zones without a speed limit reduction, the percentage of vehicles exceeding the speed limit was in general lower inside the work area than upstream by 22%. Moreover, Miglets found that at work zones, not only the speed levels are important parameters but also the speed variance. They reported that the safest traffic flow at work zones occurs when all vehicles are traveling at approximately the same speed. When speed variance increases, motorist crashes tend to increase. This suggests that the safest work zones are those with the smallest increase in the upstream-to-work-zone speed variance. When they compared the speed variance within the work zone with the variance upstream-to-work-zone for different levels of speed limit reduction they found the minimum percentage increase in speed variance for a speed limit reduction of 10 mph (16 km/h). For work zones without a speed limit reduction, the speed variance within the work zone was on average 61% higher than that recorded upstream.

Temporary speed limits should induce the drivers to reduce the driven speed but this does not necessarily imply that lower speed limits lead to lower speed variances. Considerations must, nevertheless, be given to the question whether or not a speed limit reduction is adequate enough to provide for the safety of the road workers.

The results presented above clearly show that the speed and the speed variance of the traffic through a work zone affect the safety of road users and road workers in the work zone. However, several questions are still to be answered. What is not clear is which speed limit and speed variance provide the best safety for different work zone types, regions, vehicle fleets, etc. Moreover, the question is which speed management method is best suited for delivering the desired speed distributions. The present paper addressed this latter question with the objective to provide a best practice document that can be applied across Europe with recommendations on how to effectively manage speed through roadwork zones.

3. Methods

Partners from five different EU member states were participating in the ASAP project which ran from February 2013 to January 2015. The project has four technical work packages and the structure of the project can be seen in Fig. 1.

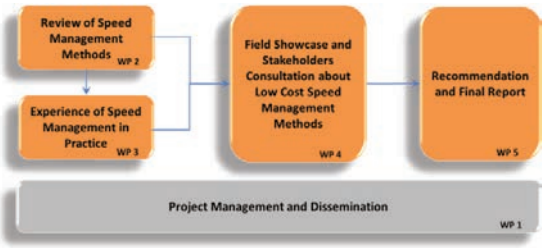

Fig. 1. Structure of the ASAP project.

The ASAP project used a wide variety of methods to gather information and knowledge about efficient speed management methods in work zones. Current guidelines and literature were collected and analysed as well as data from work zones. Stakeholder interests were reviewed and demonstration projects were conducted.

Initially both theoretical and practical information were gathered within the work package 2, Review of Speed Management Methods (La Torre et al., 2013). About 270 research reports and scientific papers, as well as national guidelines were identified, reviewed and gathered in a unique database where all the documents were classified based on their main topic, the authors, the title, the references, the year of publication and the status (“ongoing” project or “completed”). The database can be downloaded from the ASAP website (http://asap.fehrl.org/).

Work package 3, Experience of Speed Management in Practice (Saleh et al., 2014), aimed at providing knowledge and guidance from experience with speed management programs and specific measures in roadwork zones, including on-going projects, and identifying the practical usability and effectiveness of some specific speed control systems and measures preferred by the National Road Administrations. Here detailed existing data and results from speed management systems in use were gathered and analysed. To achieve this objective, a data collection related to work zones in Europe and the USA was conducted. To quantify the increased risk of work zones (if any), an analysis of Italian motorway accident data was also carried out. This analysis provides information on the change in expected

crash frequencies associated with the installation of work zones. The aim of this study was to evaluate the effect of different work zones' layout configurations on fatal and injury crashes. The analysis was carried out in a "pre-work zone" and a "during-work zone" study on a sample of 30,389 work zones installed along the Italian motorway network managed by Autostrade per l'Italia in the period 2007–2012.

The literature review, the data collection and the Italian study on motorway crashes resulted in a selection of low cost speed management methods that were either demonstrated in field showcases in the Czech Republic and Belgium or tested in a driving simulator study in Italy in work package 4 (Cocu et al., 2014). Conclusions from these first steps have also been considered to identify optimal showcase conditions (e.g. work zones' layout configurations). The showcase in the Czech Republic was performed on the D1 motorway between Prague and Brno during its reconstruction. The following speed management measures were tested:

- Information on speed limit/actual speed (LED trailer) (along the work zone)
- Advanced warning (LED trailer) (1.6 km upwards the transition area)
- Display of actual speed (moveable dynamic sign) (along the work zone)
- Information "SPEED MEASUREMENT" (Temporary road sign) (1.7 km upwards the transition area)
- Presence of the POLICE (around the transition area).

In Belgium, speed monitoring campaigns were carried out on E42/A15 between Daussoulx and Sambreville (20 km) and on E34/A21 between Zoersel and Oelegem (10km). On E42/A15, the effect of a semi-mobile visible speed camera was investigated and on E34/A21 speed data for two different roadwork layouts (1: crossing of central reserve, 2: a shift of the trafficed lane to the right) were recorded.

Five different configurations of a work zone crossover have been analyzed in the driving simulator of the Road Safety and Accident Reconstruction Laboratory (LaSIS) of the University of Florence (Italy). The analyzed infrastructure was a typical 2+2 lanes motorway with a standard speed limit of 130 km/h. Two different speed limit sequences (130–110–90–60–40–80–60–40–130; and 130–110–80–60–80–60–130; respectively), two different opening widths of the median barrier (40 m and 80 m), and two temporary lane widths (3.75 m and 5 m) were tested within the five configurations (Cocu et al., 2014).

Furthermore, in this work package stakeholders were consulted on the subject of appropriate speed and associated parameters. The aim was to ensure that the correct document format was prepared to validate the first steps of the development of a framework for European Speed Management Guidelines. The consultation included both a questionnaire sent to contacts in 14 European countries, and a 2 hour webinar with representatives from all the ASAP partners and five NRA and contractor representatives.

In work package 5, the project findings were analysed and summarized and a best practice guide/check list was set up (Sörensen et al., 2015). The basis of the analyses was the impact of individual measures. The different analyses performed during the project gave a number of implications for the development, layout and dissemination of the ASAP results in general and the ASAP guidelines in particular.

3.1. Limitations

The intention of the ASAP guideline is to provide a tool for choosing the best measures to achieve appropriate speed behaviour in work zones, with the limitation that capacity and construction needs have not been taken into account. Furthermore, the scope of the ASAP guideline must be taken in the context of work zone design procedures, national laws, and the responsibilities of third parties such as the police and construction companies. The ASAP guideline assumes that the initial roadwork speed management procedure has been carried out, including the important step of deciding the appropriate speed level scheme. Hence, the guideline focuses on assigning the speed management measure(s) to achieve the desired speed levels. Furthermore, the scope of the guideline is the effect of individual speed management measures, whereas combinations of measures are only briefly dealt with.

Unfortunately, data covering the speed management measures impact on vulnerable road users were scarcely found in this study and consequently the user has to pay extra attention to the safety of this road user group when choosing speed management measure(s).

4. Results

The ASAP guideline can be used for choosing the best methods to achieve appropriate speed behaviour in work zones. Before using the ASAP guideline, capacity and construction needs, national rules and road worker/road user safety aspects must be considered. Within this initial process, decisions are taken about the temporary lane

management, about safety equipment and signing to be installed and about the most appropriate speed regime. After this initial roadwork speed management procedure, the ASAP procedure simply supports the assignment of the speed management method(s). This assignment is preferably carried out in the planning phase before establishing the work zone, as quality assurance that the work zone speed management measures chosen are appropriate. However, if discovering that the measures currently in use are not efficient enough in reducing the speed levels the guideline can come in handy. Hence, if the appropriate speed is not achieved or is not likely to be achieved, the ASAP guideline can be used to find other or complementary recommended speed management measures.

The basic conditions to achieve appropriate speeds levels at roadwork sites may be summarized as follows:

- the decided appropriate speed levels are coherent with the local roadwork design, and the road and pavement characteristics;
- the decided appropriate speed levels are credible at each area along the roadwork site, including not only the work zone area but also the advanced warning area and the transition areas;
- the risk of exceeding the appropriate speed level is reduced and the speed variance is low, so that the accident and injury rates become low.

The ASAP procedure of roadwork speed management is presented in Fig. 2.

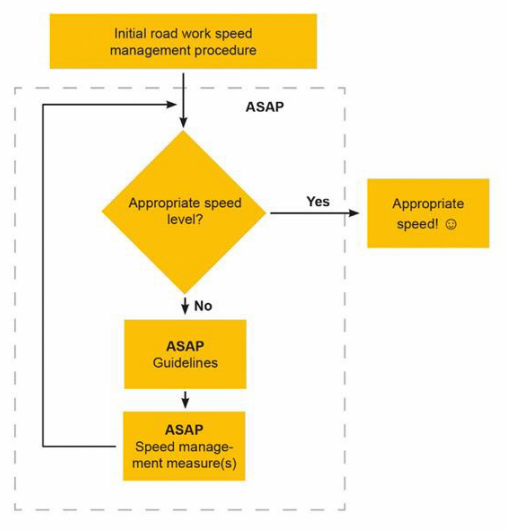

Fig. 2. The ASAP procedure of roadwork speed management.

Measures for appropriate speed in work zones suggested by ASAP are listed in Table 1. Moreover, the speed reductions with and without each measure that were reported in the studied literature have been compared and the measure's potential additional speed reduction is presented in the same table. Some of the speed management measures reduce speeds by only a few kilometres per hour compared with a work zone without this particular measure. However, even when only small speed reductions are achieved, these reductions may still be crucial when it comes to worker safety. In addition, drivers are alerted to an upcoming work zone or work zone related hazard.

Most of the measures used for controlling work zone speeds have shortcomings in terms of effects. Hence, combinations of measures are often used and usually increase the effect.

The measures in the ASAP guideline are classified based on their suitability on different road types and due to different roadwork characteristics (see Appendix A). The classifying parameters were the road type, the work type and the location in the roadwork:

- road type (motorway and dual carriageway, single carriageway)
- roadwork type (long-term roadwork (> 3 days), short-term static roadwork (≤ 3 days) and intermittent or moving roadwork)
- location of measure in roadwork (advanced warning area, transition area and work zone area)

Table 1. Speed management methods – potential additional speed reduction compared with the situation without the measure.

Speed management method	Potential additional speed reduction*
1. Temporary speed limit reduction – Static speed limit sign	Low–medium
2. Temporary speed limit reduction – Variable speed limit sign	Low–high
3. Advisory speed sign	No data
4. Automated speed enforcement – Spot speed cameras	Low–medium
5. Automated speed enforcement – Section control	No data
6. Driver speed monitoring display	Low–medium
7. Speed camera with worker warning	No data
8. Speed camera sign	Low
9. Police presence	Low–high
10. Police dummy	Low
11. Graduated fixed penalties	Low
12. Chicanes	No data
13. Crossover design	Not applicable
14. Narrowed lane widths	Low–high
15. Temporary separation of directions	Low
16. One-way traffic control – Manual flagger	Medium–high
17. One-way traffic control – Automated signal devices	No data
18. One-way traffic control – Pilot vehicle	No data
19. Rumble strips – adhesive	Low
20. Rumble strips – portable	Low–high
21. Optical speed bars	Low
22. Variable message signs	Low
23. Emotional messages	Low

* The sizes of the speed reduction listed above are based on various numbers of studies and the results vary considerably.

Depending on the type of road and the type of roadwork, the ASAP guideline recommends measures and provides a description of each measure including the measure's advantages, application fields, expected impact, on-site deployment issues and cost components (see Fig.3). Part of this information comes from the showcase experience (Cocu et al., 2014) that ended with a series of practical considerations related to the implementation of the selected measures and with relevant leanings about speed data collection and testing sites.

The objective of ensuring a high safety level cannot be fulfilled until an appropriate speed is achieved. The guideline provides solutions for achieving appropriate speed on different road types and roadworks, independently of country. This information is useful for all national and local road administrations and contractors, and provides them with a choice of speed management measures that have proven to be effective in several countries.

Detailed results from the different work packages can be found in the deliverables: La Torre et al., (2013), Saleh et al., (2014), Cocu et al. (2014) and Sörensen et al. (2015), and in Thomson et al. (2014).

Description:
- Actual speed & short warning text;
- Portable or on a trailer;
- Possible integration of a license plate recognition system

On-site deployment conditions:
- Power supply or non-autarkic solution;
- Safe location (authorisation?) & equipment stability

Cost components :
- Investment from around 3.000€ for portable solution to several 10.000€ for motor powered trailer.
- Travel and person costs for maintenance (if battery powered) or plugin to the grid or diesel consumption;
- Renting solutions are also usually possible.

Fig. 3. Driver speed monitoring display – type of information delivered in the guideline (see Appendix B for a full description).

5. Discussion and conclusions

The ASAP results must be seen in the context of work zone design procedures, national laws, and the responsibilities of third parties such as the police and construction companies. The data analysis in work package 3 suggested that the development of uniform European guidelines to standardize work zones could be wished for but is not an easy task, given the diversity of rules, roads and traffic conditions among nations and regions. The stakeholder consultation confirmed this result but at the same time the stakeholders expressed their interest in elements leading to more homogenous work zone layouts between countries. The stakeholders that were consulted also expressed the opinion that the results from ASAP can be useful not only for national road administrations and contractors but also for municipalities.

The ASAP guideline is neither expected nor requested to replace existing guidelines. The information from ASAP is instead regarded as an important support document to existing guidelines, and as a useful input to future revisions of the connected relevant guidelines. The ASAP project should provide a guide not for setting the speed limit but for informing about the important decision on appropriate speed levels, about relevant criteria used across EU for setting the speed limit regime but most of all; a guide for choosing the speed management measures that will result in appropriate speed behaviour in work zones.

It can be stated that most of the speed management measures reduce speeds – although sometimes only by a few kilometres per hour, compared with a work zone without this particular measure. However, even when only minor speed reductions are achieved, these measures may still effectively alert drivers to an upcoming roadwork or a hazard within a roadwork, thereby increasing the safety of both road users and road workers.

In general, it is positive to have additional information about the work zone location and especially the beginning of the work zone (e.g. specific road signs in the advanced warning area), together with clearly visible optical signals and physical measures/treatments. This lead the driver to a safer driving behaviour and raises the awareness of the on-coming variation in the road trace. A narrowed lane with additional haptic measures (such as rumble strips) is e.g. giving a clear hint to the driver – to slow down must be the logical consequence for each driver. In some countries, and especially on safety critical road sections where the acceptance of speed limitation and/or the degree of penalty seems to be low, other more severe measures could decrease the number of speeding vehicles and ensure a better reliability of the overall work zone safety. Different types of physical measures like s-shaped chicanes, or enforcement like speed cameras, radar enforcement, section control or police presence are examples of such measures. All speed and safety related effects of any measure, if single ones or combined, are strongly dependent on the traffic volumes, the type of vehicle fleet, the general speed compliance of drivers in this region, the quantity of enforcement, the perceived risk of being fined for speeding, and how deterrent the penalties are perceived. It is common use to have more than one single speed reduction measure in work zones, but a general conclusion on what combinations to use cannot be drawn from this study. Based on the findings within the ASAP project, however, potential positive effects of combined measures are indicated.

In conclusion, the ASAP guideline should be regarded as both a supplement to existing guidelines and a basis for new revisions of national guidelines. Packaged as a stand-alone reference document the ASAP guideline lists recommended measures and provides a fact sheet for each of the measures, with description, advantages, application fields, expected impact, on-site deployment issues and cost components. Further studies are required in order to address the delicate matter of deciding the appropriate speed, the important consideration of vulnerable road users at roadwork sites, and the effect of combined measures. The development and improvements of the ASAP guideline should be an ever ongoing process, involving both researchers and practitioner all over Europe.

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Appendix A. Recommended measures depending on road type and roadwork characteristics

Table 2. Recommended Measures on motorways + dual carriageways (MV) and on single carriageways (SCW).

Duration	Advanced warning area	MW	SCW	Transition area	MW	SCW	Work zone area	MW	SCW
Long term (> 3 days)	1. Temporary speed limit reduction – Static	●	●	1. Temporary speed limit reduction – Static	●	●	1. Temporary speed limit reduction – Static	●	●
	2. Temporary speed limit reduction – Variable	●	●	2. Temporary speed limit reduction – Variable	●	●	2. Temporary speed limit reduction – Variable	●	●
	8. Speed camera sign	●	●	3. Advisory speed signs	●	●	3. Advisory speed signs	●	●
	11. Graduated fixed penalties	●	●	4. Spot speed camera	●	●	4. Spot speed camera	●	●
	21. Optical speed bars		●	6. Driver speed monitoring display	●	●	5. Section control	●	●
	22. Variable message signs	●	●	9. Police presence	●	●	6. Driver speed monitoring display	●	●
	23. Emotional messages	●	●	10. Police dummy	●	●	7. Speed camera with worker warning	●	●
				12. Chicanes	●		9. Police presence	●	●
				13. Crossover design	●		10. Police dummy	●	●
				17. Automated signal devices		●	14. Narrowed lane width	●	●
				18. Pilot vehicle		●	15. Temporary separation of directions	●	●
				19. Adhesive rumble strips	●	●			
				22. Variable message signs	●	●			
Short term (≤ 3 days)	1. Temporary speed limit reduction – Static	●	●	1. Temporary speed limit reduction – Static	●	●	1. Temporary speed limit reduction – Static	●	●
	8. Speed camera sign	●	●	3. Advisory speed signs	●	●	3. Advisory speed signs	●	●
	11. Graduated fixed penalties	●	●	6. Driver speed monitoring display	●	●	7. Speed camera with worker warning	●	●
	22. Variable message signs	●	●	9. Police presence	●	●	9. Police presence	●	●
	23. Emotional messages	●	●	10. Police dummy	●	●	10. Police dummy	●	●
				16. Manual flagger		●	14. Narrowed lane width		●
				17. Automated signal devices		●	22. Variable message signs		●
				18. Pilot vehicle		●			
				20. Portable rumble strips		●			
				22. Variable message signs	●	●			
				23. Emotional messages		●			
Intermittent-Mobile	22. Variable message signs	●	●	3. Advisory speed signs	●	●	3. Advisory speed signs	●	●
				6. Driver speed monitoring display	●	●	6. Driver speed monitoring display	●	●
				7. Speed camera with worker warning	●	●	7. Speed camera with worker warning	●	●
				22. Variable message signs	●	●	22. Variable message signs	●	●

Appendix B. Recommended measures for appropriate speed in work zone – example of data provided within the ASAP guideline (extract of deliverable 5.1)

Table 3. Driver speed monitoring display (description; main advantages, main recommendations, application fields, expected impact, on-site deployment/operational issues; cost components).

Measure name
Driver speed monitoring displays
Description
Speed monitoring displays (SMD), are usually stand-alone systems that can be installed individually, or in series (Figure). Different systems are on the market, e.g. self-contained trailer unit equipped with speed detector and a display. The systems are typically battery powered to last at least one week. The speeds of approaching vehicles are displayed on LED panels, usually along with the posted work zone speed limit, and messages like "Your Speed is …", "Watch speed", etc..

Figure. Mobile speed monitoring display showing the drivers' speed and a message. Left: message "ZPOMAL" (Reduce your speed), photo: CDV. Right: "Här gäller 30" (Current limit 30) photo: SNRA.

Main advantages
• Effective in lowering speeds • Increases harmonisation of speeds • Increases speed limit compliance • Increases the vigilance considerably
Main recommendations
• The effect of a single VMS may be reduced with distance from the sign (low halo effect), but the effect can often be sustained with two or more VMSs. • "Personal" messages (like "Your Speed is …") seem to be the more effective than impersonal messages (The speed is….). • Higher effectiveness, if supported by periodic police enforcement. • If combined with text, language dependent.
Application fields
• Should be placed close to the area where the speed reduction is needed.
Expected impact
• The potential speed reduction ranges from 3 to 12 km/h. • Effective speed reduction only for a short section.
On-site deployment/operational issues
• Battery or other source of energy needed.
Cost components
• High investment cost • Rather low operating costs • Can be rented • Not labour intensive

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