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Speed management at Work Zone - Field studies and stakeholder's survey

Deliverable 4.1
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CEDR Call2012: Safety

ASAP
Appropriate Speed Saves all People

Deliverable 4.1: Practical information from field studies and stakeholder's survey

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EXECUTIVE SUMMARY

An important step in the development of practical recommendations on Speed management at Work Zone is to identify promising low cost speed management measures and to carry out on-field show cases to demonstrate good practice. As planned in the project proposal a showcase has been carried out in the Czech Republic, along a road work site on the D1 motorway. Several scenarios with various speed management measures have been implemented and monitored. Two additional (i.e. not planed in the project proposal) speed monitoring actions have been carried out along two major road works executed on Belgian motorways. The road work circumstances and the speed management measures deployed on these sites provided the opportunity to complement the scenarios tested on the Czech site. Due to national regulations or road work site constraints some important parameters, such as speed limits, lanes width or geometry of the lane deviation when crossing the central reserve can't be easily tested in a field showcase. A complementary analysis (also not planned in the project proposal) has been conducted through an experiment in its driving simulator.

Analysis based on 6 hours' time periods confirmed that the period of the day is an important factor when looking at speed behavior and that speed amplitudes observed between different periods of the day are usually higher than between periods with and without activation of a specific speed management measure.

From the studies it appears that the use of a speed camera sign in the advance warning area clearly impacts driven speeds, that mean speeds and standard deviation are also positively impacted by the (speed activated) VMS trailer installed in the work zone as well as by the Police car presence. The experiment in the driving simulator demonstrated that the installation of a Variable Message Sign (VMS) may provide some effects on reducing speeds; the impact being maintained within the first part of the advance warning area. However the VMS loses its effectiveness in the following sections. The presence of an Automatic Speed camera also seems to have an impact on the mean speed and on the proportion of drivers exceeding the temporary speed limit. This is particularly visible for daytime traffic. However it is likely that the speed camera has a local impact that decreases when progressing along the work zone. To what extend still needs to be determined.

Alternative geometries of the central reserve crossing and speed limit schemes have been tested in controlled conditions. This part of the study interestingly indicates that even if a wider opening of the central reserve combined with a slightly higher speed limit result in an increase of the mean speed, both the speed variance from upstream to work location and mean deceleration around the by-pass entrance are much lower than in the reference situation.

Important conclusions have also been drafted about the deployment of the speed management measures and speed monitoring devices. They demonstrate the absolute need of communication and operational plans drafted at the early stage of the road work planning to identify and commit the various actors, to schedule the deployment of equipment, to efficiently operate the various devices and organize the data collection.

Deploying and maintaining speed monitoring equipment and speed management measures remains a time consuming task. One important element with such speed monitoring campaigns is linked to the location of the speed detectors. As far as possible their location should be fixed by monitoring needs only to be able to evaluate the spatial effectiveness of the speed management measure. This is an important deployment issue that must be considered for all further implementation activity.

Based on the knowledge gathered and the analyses of data in the first half of the project external experts have been consulted. This was an important step to ensure that the recommendations are in line with the needs and requirements of the NRA´s and considered possible to implement.

During the consultation it was made clear that the ASAP guidelines are not expected, nor requested to replace existing guidelines. The information from ASAP was instead regarded as an important support document for existing guidelines and as useful input to future revisions of the connected relevant guidelines.

Setting the speed limits does not guarantee a low speed in work zones. If the speed level is too high for the road works situation, complementary measures have to be taken that can assure a sufficiently low vehicle speed. Speed cameras and physical reductions give examples on such measures. When it comes to graduated penalties there are difficulties in interpreting the results from different states in the USA and no standardized results are available. Hence, this measure cannot be recommended as a stand-alone measure but has to be combined with other measures such as information about the amount of the fine for speeding in work zones, and the risk of being fined has to be perceived as high.

Many countries do not have detailed data available for assessing work zone safety and ASAPs experience in data collection in the data review (WP3) and field showcases (WP4) will be important resources for future users. Moreover, the planned activities concerning work zones in the US; a new project about “Work zone speed data and crash data practices” that is about to start; could be of interest for the CEDR organization.

The ASAP project should provide a guide not for setting the speed limit but for choosing the best speed reducing methods that will result in appropriate speed in work zones. Appropriate speed is achieved when; the desired speed is achieved, speed variance is low, and when accident and injury rate is low. Desired speed might be the speed limit through the work zone, but can as well be the recommended speed or the speed level expected from the speed reducing measures. Level of desired speed should never be higher than the speed limit.

1 INTRODUCTION

It is important that European road users are presented with consistent traffic control techniques, regardless of where they travel within Europe. Speed management of traffic through work zones is important for the safety of both the road user and road worker. A work zone will entail deviations from normal travel in a discrete road section and appropriate speed is needed to ensure that the driver can navigate the vehicle through the work zone routing, particularly if there are abrupt lateral deviations from road design norms. Without proper control of the vehicle, the driver may cause the vehicle to enter the restricted areas of the work zone. Vehicle encroachments into these areas can cause injury to the car passengers or the road worker. Selection and control of traffic speeds in work zones are thus crucial components for road safety.

A transnational resource for best practice guidelines and financial implications of work zone speed control is not available in Europe. A common information source should be made available if European road users and road workers are to have the best level of safety, regardless of the country or region. The **ASAP** project - ***Appropriate Speed saves All People*** - was designed to address the issues of speed management in work zones.

The ASAP project runs from February 2013 to January 2015 with funding from the CEDR "TRANSNATIONAL ROAD RESEARCH PROGRAMME Call 2012 - Safety: Safety of road workers and interaction with road users. The project activities are divided into the following working steps:

- State-of-the-art/ Archival Research

  The first part of the project was to gather knowledge on speed management measures that have been investigated in previous studies and also experiences on speed management measures that are currently being used in different European countries, and also in USA and Canada. A number of different topics were covered such as: Guidelines and criteria; Methods to manage and control vehicle speed at road works; Enforcement strategies such as "Graduated fixed penalties" for enforcing speeding in road works zones. The result of this first step is reported in Deliverable 2.1 "State of the Art on Speed Management Methods".

- Data-analysis

  In a second step, data were gathered from different countries to investigate the correlation between work zone layouts, work zone management and vehicle speeds. Results are reported in Deliverable 3.1 "Experience of Speed Management in Practice".

- On-field showcase and Stakeholder consultations

  Based on the knowledge gathered and the analyses of data in the first half of the project a first set questions and discussion points were developed to be used for external experts and stakeholder consultations. This is an important step to ensure that the recommendations are in line with the needs and requirements of the NRA´s and considered possible to implement. Another step in the development of practical recommendations is to identify promising low cost speed management measures and to carry out on-field show cases to demonstrate good practice.

  The conclusions emerging from the on-field show cases and stakeholder consultation are presented in this report – Deliverable 4.1 "Speed management at Work Zone - Field studies and stakeholder's survey".

- Development guidelines for road works/Documentation

The global objective of the CEDR call for research project is to develop guidelines and information that will allow national and regional road operators, contractors, and authorities to deliver the best safety for the road users and road workers. Using the combinations of the previous research methodologies, the project results will be reported in appropriate formats for practical implementation.

2 OVERVIEW OF THE REPORT

This report present all the actions carried out during the on-field show cases, and their results, as well as the stakeholder consultation organised at mid-term to ensure that the correct document format is being prepared to validate the first steps of the development of a framework for European Speed Management Guidelines.

The showcase scenarios depend on the knowledge gained during- and on the results from the work packages 2 and 3 about what work zone types or speed limit schemes are critical for road worker and road user safety and about how much some speed management techniques are efficient. Various constraints related to the roadwork sites available for testing and to the regulations in force in the concerned country also impact the way different scenarios are being planned. Building the showcase scenarios is the main focus of the chapter 3.3.

Field and simulator studies are fully described in the chapter 3.4. Showcase and simulator study results and conclusions are presented and discussed in chapter 3.5.

Based on the experience gained during the showcase the chapter 4 discusses some main implementation issues related to the speed management methods tested/studied during the showcases. Doing so it aims to contribute to the recommendations being developed in WP5 about effective strategy and measures to manage speed through road works zones.

Chapter 5 describes and presents the results from the stakeholder's consultation actions:

- a targeted stakeholder survey of NRAs and road operators used to better understand the interpretation of the existing guideline factors and what could be used in future guidelines;
- a discussion among the ASAP partners and a group of stakeholders during a webinar;
- a consultation (in addition to the review conducted within WP2) of an American expert on the topic graduated penalties.

Finally the sixth chapter synthesises the main conclusions and perspectives arising from this comprehensive work package that mixed on-field testing and experts' consultation, considered both as necessary practical elements to drawn the project recommendations.

3 DETAILED SHOWCASE REPORT

3.1 Introduction

The 4th work package of the ASAP project intends to showcase some “low cost” speed management measures identified during the initial steps of the project as good practices in the driver information/warning/enforcement field.

Basically, the showcase scenarios depend on the knowledge gained during- and on the results from the work packages 2 and 3 about what work zone types or speed limit schemes are critical for road worker and road user safety and about how much some speed management techniques are efficient. However various constraints related to the roadwork sites available for testing and to the regulations in force in the concerned country also impact the way different scenarios are being planned.

Considering the experience gained by the Centrum dopravního výzkumu, v. v. I.(CDV) during the ViaZONE project (*Increasing traffic flow and transit capacity at highway and expressway locations with temporarily limited transit by means of mobile cooperative ITS systems – Mobile active traffic management*; http://www.viazone.cz/en), the ASAP showcase was initially planned (in the project proposal) to be carried out along a Czech motorway and with some of the equipment developed and tested in the framework of the ViaZONE project. The Czech showcase has been carried out on a road work site along the D1 motorway, i.e. the main highway of the Czech Republic currently connecting Prague and Brno. As detailed in the chapter 3.4.1, several scenarios with various speed management measures have been implemented and monitored.

Additional (i.e. not planed in the project proposal) speed monitoring actions have been carried out by the Belgian Road research Centre (BRRC) along two major road works executed on the E42/A15 and on the E34/A21 Belgian motorways. The road work circumstances and the speed management measures deployed on these sites provided the opportunity to complement the scenarios tested on the Czech site. However being not scheduled from the initial stage of the project these activities were less embedded in the road work project than on the Czech D1 and therefore mainly consisted in traffic monitoring campaigns. The monitoring plan deployed along the Belgian sites was also simpler than on the CZ site. The scenarios monitored in Belgium are described in the chapters 0 and 3.4.3.

Due to national regulations or road work site constraints some important parameters, such as speed limits, lanes width or geometry of the lane deviation when crossing the central reserve can’t be easily tested in a showcase. The University of Florence (UNIFI) therefore proposed to also carry out a complementary analysis (also not planed in the project proposal) through an experiment in its driving simulator. The scenarios tested in the simulator are described in the chapter 3.4.4.

3.2 Showcases objectives

The main objective is to demonstrate how some of the relevant measures may be deployed and how efficient they could be in a European road work environment. This action gives an added value to the final recommendations; making them practical and also contributes to fill in some knowledge gaps in this field.

Work packages 2 and 3 demonstrated that managing speed along a road work environment is a complex task, typically because the parameters that may influence the road user behaviour and safety, as well as road workers' safety, and particularly the driven speed, are numerous.

Some of these parameters being high-level are usually fixed:

- The type of road;
- The type of road work (mobile, stationary, short/long term);
- The work zone length;
- The lane management;
- The road work layout (lane closure, lane deviation, diversion on opposite lane
- The availability (or not) of lay-bys, shoulders, emergency lanes;
- The number of entrances/exits in WZ;
- The traffic volume, vehicle classes and WZ capacity.

Some other parameters may be subject to variation, depending on the country regulations; i.e.:

- The (national) speed limits;
- The location of speed limit signs (distance to WZ);
- The lane width;
- The delineation and protective equipment;
- The presence of a section control;
- The range of penalties (fixed or graduated).

And finally a series of parameters are usually less constrained by standards and rules. They are typically part of Information and Enforcement devices or methods:

- Variable message signs
- Pre-information
- Actual (individual) speed information
- Radar enforcement
- Police enforcement

If the first series shown above should be considered as constraints, we can't easily change or adapt it during a showcase, the two latter were typically candidate parameters to be included in the "play list" of the ASAP showcases. The following chapters will detail which ones have been tested during the 4th ASAP work package.

3.3 Building the showcase scenarios

3.3.1 Work zone type

Previous studies conducted within the ASAP project (WP3) raised some interesting concerns about critical work zone type or situation. As stated in the Deliverable 3: Experience of Speed Management in Practice, all layout configurations that involve a crossover (total or partial) are very critical and have the worst effects in terms of road safety; accident analysis shows that traffic management using lane reductions at work zones also lead to a rise in accident frequency. However there is not generally a higher accident frequency within work zones with the lane managements 4+0 and 3+1 compared to the situation when there is no work zone (provided the directions of travel are structurally separated by work zone barriers). Since those findings are inconsistent, the partners considered useful to pay attention to such types of road work layouts during the showcase. There is indeed insufficient data to unambiguously prove this statement.

The D1 motorway (CZ) and E34/A21 motorway (BE) road work sites were 4+0 schemes, the E42/A15 motorway (BE) was a 3+1 scheme and a 2+0 scheme has been implemented in the Italian Driving simulator.

D.3.1 also emphasizes that adequate lane width within the work zone, appropriate design of the median crossover and appropriate implementation of road work equipment barriers separating the directions of travel within the work zone and protected working areas are essential safety parameters. Typically the combination of temporary guard rails and low beacons has proven to be advantageous as they provide a more homogeneous speed reduction.

Such considerations have also been considered to pre-identify optimal showcase conditions.

3.3.2 Setting the Speed limit – Impact of the speed limit signs

Experience has shown that the use of signs to reduce the speed of traffic through work zones has varying degrees of effectiveness. The level of compliance to speed limits is indeed very much dependent on the credibility of speed limits (i.e. in line with the drivers' expectations). When the speed limits are credible a positive effect is expected on average driving speeds and on homogeneity of the traffic flow.

As reported in the *State of the Art on Speed Management Methods* (Deliverable 2.1) studies suggest that the safest traffic flow occurs when all vehicles are travelling at approximately the same speed, meaning that the level the road users comply with the speed limit is a crucial factor for road work safety. Migletz & al (1993)[1] indicated that speed compliance in work zones is generally higher where the speed limit reduction is lower than 16 km/h (10 mph). However the state of the art also showed that in some countries small speed reductions are used; others use multiple levels of 20 km/h (or higher) speed reductions.

The literature also mentions that speeding occurs, among other situations, when the stretch with temporary speed reduction is much longer than the actual work area, particularly if no workers are present. The location of the speed limit, as compared to the work area is therefore also an important parameter.

Conclusion for the showcase scenario

The speed limits scheme is crucial for road works safety. However this parameter is very much dependent on the regulations in place in the country and appears to be difficult to modulate. Therefore the decision to complement the showcase in the Czech Republic with two additional speed monitoring actions in Belgium and a series of tests in a driving simulator in Italy was taken by the partners.

[1] Migletz, J. , Graham, J.L., Harwood, D. W., "Procedure for Determining Work Zone Speed Limits," National Cooperative Highway Research Program, Project 3-41, Transportation Research Board, Washington, D.C., 1993, pp. 214-218.

Being crucial for road works safety, this parameter has been included in the ASAP showcases as the following table shows.

Table 1: Speed limit schemes in place in the showcases

	Speed limit scheme	Layout type	Opening width/Temporary lanes width*	Base situation
	D1 motorway, Czech Republic			
1	130→100→80	Lane deviation	2,5m / 3,15m	Static signs.
2	130→100→80→60→80	Crossing of the central reserve	80m	
	E42/A15 motorway, Belgium			
3	120→90→70→50→70	Lane deviation & Crossing of the central reserve	50m / 4m & 3,25m	Static signs, fixed & mobile VMS in the advanced warning area
	E34/A21 motorway, Belgium			
4	120→90→70	Crossing of the central reserve	+/-125m / 4,20m & 3,40m	Static signs, mobile VMS in the advanced warning area, speed display, temporary gantry, transversal rumble strip, warning VMS in the transition area
5	120→90→70	Lane deviation	- / 4,20m & 3,40m	
	Driving simulator, Italy			
6	130→110→90→60→40→80	Crossing of the central reserve	40m / 3,75m	Static signs
7			40m / 3,75m	Static signs + VMS
8			40m / 5m	Static signs
9	130→110→80→60→80	Crossing of the central reserve	80m / 3,75m	
10			80m / 5m	

*: temporary lane(s) width at the start of the lane deviation

3.3.3 Speed management techniques

3.3.3.1 Informational measures

One way to address appropriate speed limits is to provide motorists with information related to work zones, worker safety, speed limits, penalties for traffic law violation, real-time speed feedback and hazard warnings. The measures commonly adopted in this area are: Regulatory speed limit signs; Speed monitoring displays; Variable message signs; Flaggers.

Speed monitoring displays and Variable message signs (portable ones) are easily implemented on site and at relatively low cost level. They are less subject to regulation in the road work signing standards than speed limit signs and, as explained after they also offer a good potential to improve speed limit compliance. Both have been selected to be tested during the showcases.

Speed monitoring display (SMD)

SMDs are usually stand-alone systems that can be installed individually, or in a series. The system consists of a self-contained trailer unit equipped with radar sensors (or simply in a portable radar display) to measure the speed of approaching vehicles. The display boards are generally not used to enforce the speed limits. Approaching vehicle speeds are usually displayed on LED panels along with the posted work zone speed limit, and a message stating like “Your Speed is …”, “Watch speed”, etc.

Literature shows that display trailers are very effective in lowering speeds, increasing uniformity of speeds, and increasing speed limit compliance. Before/after studies conducted around the World show mean speed reduction ranging between 3 to 12 km/h, depending on the SMD location and road work characteristics.

Variable message signs (VMS)

A device commonly used to increase driver awareness in work zones are Variable Message Signs. VMS can provide drivers with real-time information about conditions, and can be particularly useful at work zones where unexpected traffic or detour situations exist. Often a variable message sign is equipped with radar sensors and has the capability to determine the speeds of approaching vehicles. Portable variable message signs (PVMS) are most often found in work zones, providing special instructions, warnings, or other information to motorists.

In general the use of VMS Message sequences has shown to reduce the mean speed and the 85th percentile of speed. VMS effectiveness on reducing speeds is strictly connected to placing a message on the sign only when there is a specific activity or condition that really requires the message. The VMS location would be dependent on the characteristics (speed, traffic volume, road geometry) of the specific work zone.

Some literature references report that mean speed reductions of around 4 km/h can be achieved with such a system. Better speed limit compliance is even achievable when the VMS is equipped with radar sensors and address a variable message to the drivers, depending on their speed. “Personal” messages (like “You are speeding, slow down”) seem to be the most effective.

3.3.3.2 Physical measures

Physical devices are used to influence motorists’ speeds by placing traffic calming devices, marking or equipment on the road surface which modify the layout geometry or generate sound, vibration or optical illusion that affects drivers’ perception of speed.

Rumble strips create an audible, visual, and physical alert when driven over and are therefore intended to warn drivers of an approaching work zone where they may be required to stop, merge, or simply slow down. Literature mentions pilot tests with portable plastic rumble strips that did create significant additional speed reduction, more particularly for cars.

In Flanders transversal rumble strips (marking) are usually implemented on long term road works on motorway. Such system placed close to the transition area was part of the speed monitoring campaign carried out on the E34/A21 motorway showcase (**Figure 1**).

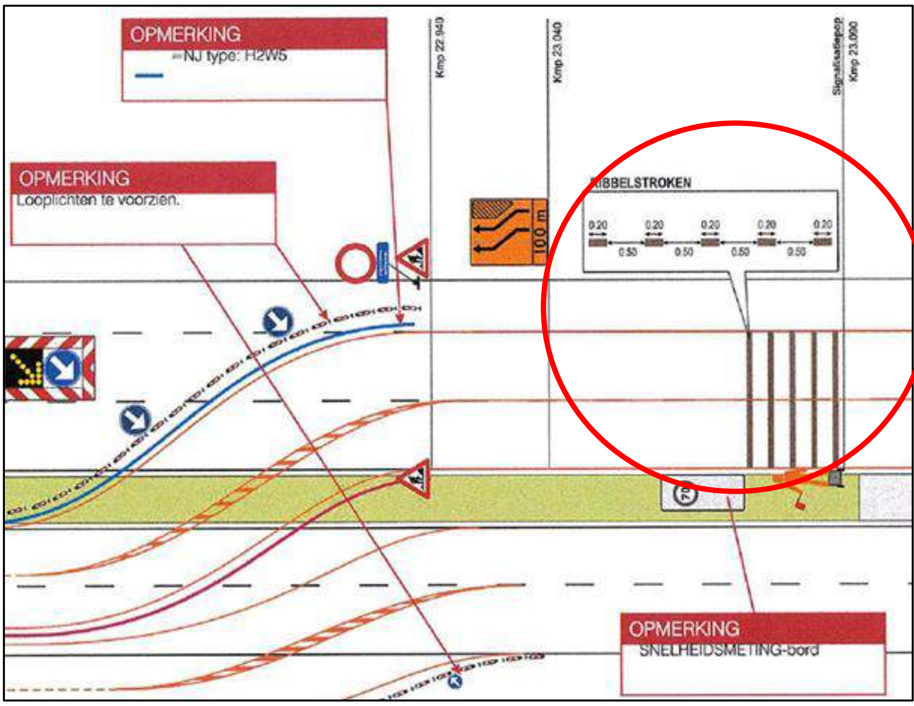


Figure 1: Transversal rumble strips (marking) implemented for the E34/A21 road works

<u>Narrowed lane width</u>

Narrowed lanes leave less lateral distance between vehicles in adjacent lanes or between vehicles and shoulder obstructions, increasing motorists' attention and inducing motorists to reduce speeds. This can be accomplished using a variety of channelizing devices, including markings, delineators, traffic cones or temporary barriers.

A study conducted on work zones on two-lane rural roads in Italy[2] show that drivers do not obey the temporary speed limit and that they reduce speeds only when the lane width is reduced, resulting in high deceleration rates.

By narrowing the lane width, it is therefore seems possible to create moderate speed reductions throughout the entire length of the narrowed section. This interesting measure is also a relatively low cost form of speed control for long-term projects since there is usually very little management cost to maintain it. However narrowing lane widths can reduce roadway capacity. There is also a greater possibility of vehicles striking the cones or other devices, which could increase the number of crashes in these work zones. The effect particularly depends on percentage of trucks traffic.

Based on this appreciation it has been decided to further test the impact a lane width modification on the driver speed behavior in the UNIFI driving simulator. Due to national regulations or road work site constraints such a parameter can't be easily tested in a real site showcase.

<u>Optical speed bars/markings</u>

Several studies have been conducted with driving simulators and some on real sites to evaluate the effectiveness of this treatment in terms of speed reduction. As reported in the

[2] Perco P., Dean S., 2012. "Driving Speed Behaviour Approaching Road Work Zones On Two-Lane Rural Roads". Procedia - Social and Behavioral Sciences, Volume: 53. pp. 673-682

ASAP State of the Art (deliverable 2.1) several of the measures tested were effective for reducing speeds in a normal road work environment. However there are quite fewer studies concerning the effectiveness in work zones.

Geometry of the transition area

A traffic management solution characterized by a change in the alignment of the open lanes forces drivers to change directions and typically reducing their speed. For the purpose of ASAP, two different configurations of a crossing of the central reserve coupled with a change of the speed limit scheme have been tested in the UNIFI simulator (described in chapter 3.4.4).

3.3.3.3 Enforcement measures

Enforcement measures are used to enforce speed limits by automated speed monitoring, speeding detection, imposition of violation fines, and presence of police cars. In general police enforcement is perceived to be one of the most successful work zone speed reduction strategies. There are also some speed reduction measures that are unlikely to be effective unless supported by some level of police enforcement.

As reported in the ASAP Deliverable 2.1 measures that have proven to be effective in helping to manage speeds in work zones include police presence, mobile enforcement in the work zone and automated speed enforcement. Stationary police presence and automated speed enforcement have been included in the showcases.

Stationary police presence

Literature reports higher level of speed limit compliance along work zones where a Police vehicle was parked and visible (but not necessarily doing speed control). However upon passing the police car drivers tend to return to original speeds or higher. A study[3] reported no discernible changes in speeds one, two, and three hours following police presence.

References cited in Deliverable 2.1 indicate that a combination of more than one device could improve speed compliance through the work zone.

Generally, it is beneficial to position police vehicles upstream or at the beginning of the work zone, because of its powerful effect in getting vehicle speeds down before they enter the work zone.

Automated speed enforcement

Automated speed enforcement devices utilize a radar or laser devices to detect speeds of oncoming traffic. The device takes a picture of the vehicle’s license plate (and of the driver if needed). With this solution officers do not have to pursue, or attempt to pull over, vehicles within the work zone. Spot enforcement can be labour intensive and costly with long term use. However semi-mobile speed cameras (installed for several days) are more and more used for safety sensitive road work sites.

All the studies mentioned in Deliverable 2.1 indicate that radar enforcement is effective in reducing the average speed in a construction work zone, increasing compliance with the work zone speed limit. At the same time a more stable spatial speeding distribution through

[3] Sisiopiku V.P., Patel, H., 1999. “Study of the Impact of Police Enforcement on Motorists Speeds”. Transportation Research Record: Journal of the Transportation Research Board, issue 1693. Washington, D.C., pp. 31-36.

the work zone is usually induced. However the temporal and spatial effects of such measure have not yet been widely studied.

For more detailed information check out the ASAP Deliverable 2.1: State of the Art on Speed Management Methods, Chapter 4.

3.3.4 Site constraints

The deployment of the showcase was of course dependent on the available work sites, i.e. on the road works scheduled during the study duration. The regulations in force in the concerned country also strongly impact the way different scenarios are being planned. However thanks to an early preparation of the showcase in the Czech Republic as well as to the extension of the showcase to 2 additional sites in Belgium and to the experiment in the UNIFI driving simulator it has been possible to include different speed limit schemes and to make use of the all the good practices identified during the previous project phase.

3.3.5 Methodology

Former field tests in work zones reported in the ASAP Deliverable 3: Experience of Speed Management in Practise were analysed to inform the showcase methodology. Field studies like the one reported by Spacek et al (2005)[4] were helpful to orientate data collection during the WP4 showcases.

As an example Spacek et al (2005) investigated a work zone on the Highway A1 (**Figure 2**) in the Canton St. Gallen, close to the interchange Uzwil Nord. The temporary lane management consisted in a 10 km long 4+0 lane scheme. In this field trial, two different speed limits were tested (80 km/h and 100 km/h), in addition the speed measurements were conducted once with displayed radar enforcement and once without radar enforcement for each speed limit. This consequently led to four different variants.

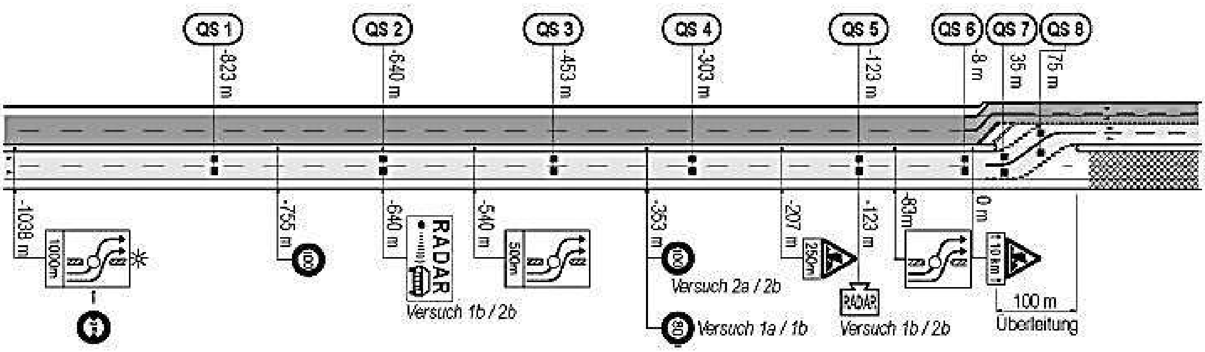


Figure 2: Field test A1 St.Gallen (Source: ETH Zürich, Baustellen an Hochleistungsstraßen Schweiz, 2005, p. 32)

Such studies provided a good reference for the subsequent field tests.

WP3 conclusions typically suggest paying attention to exit and entrance areas, crossovers and lanes deviations. The speed management measures were implemented in the vicinity of

4 Spacek P., Laube M., Santel G.; 2005; “Baustellen an Hochleistungsstraßen” Forschungsauftrag VSS 1999/127 auf Antrag des Schweizerischen Verbandes der Straßen- und Verkehrsfachleute, ETH Zürich, Zürich, Switzerland

such risky areas and to get an idea about their influence were the speed monitoring devices located close to the speed management measures.

Experience from former field testing – The ViaZONE project

Centrum dopravního výzkumu, v.v.i. deals with the possibility of temporary traffic management at road works in several projects. One of these is the ViaZONE project[5] which was performed in 2011-2013. The project analysed in detail available technologies and systems for effective traffic management at road work sites with lane closures.

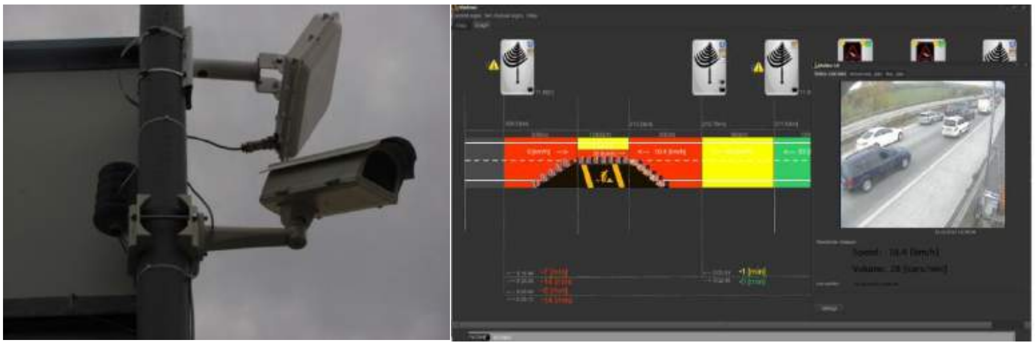


Figure 3: Portable traffic detectors (left) and controlling software of portable control system ViaZONE, which was developed and pilot tested on motorway D1 in 2013

ViaZONE designed, created and pilot tested a control system that allows smartly managing traffic at lane closures like along road work sites. Calibrated traffic models based on traffic flow measurements were created in the first stages of the system development. Their task was to verify the designed measures in laboratory conditions and to search for possible placement of detection devices and portable variable message signs, whose role is to guide traffic flow and influence drivers' behaviour.

Simultaneously, hardware elements of the system were created. They were developed tailor-made for the needs of portable systems, which met the initial criteria set by the researchers. The limiting factors for designing and developing hardware parts of the system particularly included modularity, energy independence and efficiency, flexibility, and portability. In the final stage of this project, the complex system was tested on motorway D1 between Brno and Vyškov for three months.

The tested system includes portable variable message signing, portable traffic detectors, industrial computer with minimum consumption of electric energy compatible with all detection elements, modems for data transfer, and alternative sources of energy for power supply of all parts of the system.

[5] ViaZONE was a project supported by the Technological Agency of the Czech Republic ČR TA01030305 "Zvýšení plynulosti dopravy a průjezdní kapacity vozovky v místech s dočasným omezeným průjezdem vozidel na D a R pomocí mobilních kooperativních ITS systémů – Mobilní liniové řízení provozu" (Traffic flow harmonization and increasing the road capacity in work zones on highways using co-operative portable ITS systems - Portable active traffic management)

Figure 4: Photo from ViaZONE pilot testing

The conducted research implies that the probability of a road accident occurrence at sites with traffic closures is **three times higher** than at non-restricted motorway and dual-carriageway sections. The economic losses from traffic congestions are not negligible at sites with traffic closures.

Data from this project showed considerable over speeding; it was found that driven speed was by approx. **20km/h** faster than the speed limit, even at sites where the workers are present and the width of lanes is considerably reduced. This fact is also the main reason for the occurrence of accidents and in some cases a reason for long vehicle queues.

By displaying the road sign B20a (80km/h Speed limit) a reduction of traffic flow speed by **approx**. **25% to speed around 100km/h** was achieved. Even better result during the tests was reached by displaying a warning sign A23 “queue” (speed reduced to approx. **95 km/h**). Displaying road sign B20a (100 km/h Speed limit) fails to have an apparent impact on the speed of traffic flow. Certain speed reduction of traffic flow speed was only reached in case a sign “IP21” (Limitations in the lane) was displayed at the lower LED panel on the advance warning trailer (B20a 100km/h is displayed at the upper panel).

Experience from ViaZONE shows that sufficient attention must be paid to the planning process:

- Detailed information about work zone, i.e. apart from the known data, such as traffic guiding, number of traffic lanes and their gradient, cross section of road, knowledge of traffic volumes during road works is also very important;
- Decision on the form of the system, its functions (management, warning, surveillance, etc.) and the number of components in relation to materials in previous steps.

3.3.6 Data collected and data processing

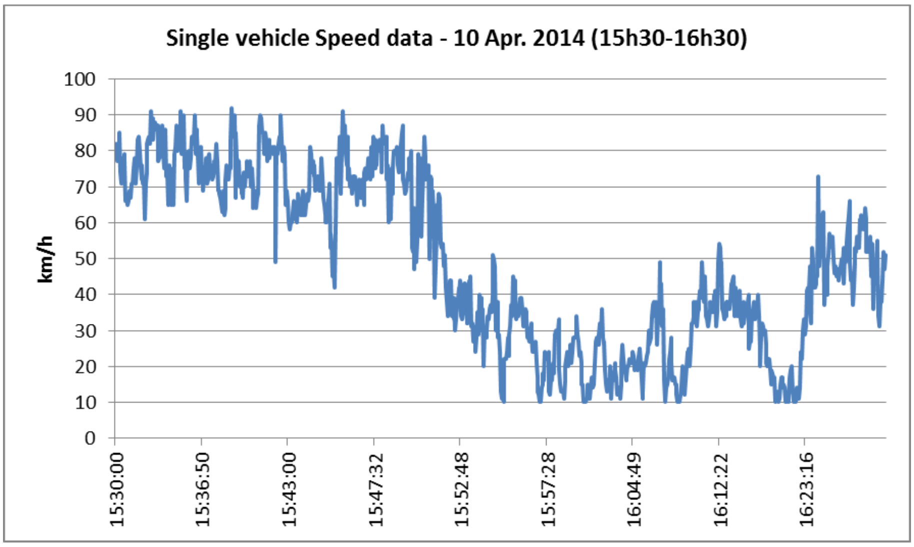
Road works may have a great impact on traffic, typically on main motorways with high traffic volume and even when the number of lane opened to the traffic remains unchanged. Congestion problems have been observed several times along the road works monitored during the showcase, not only because of the traffic intensity but also in relation to the activity carried-out in the work zone (with numerous road work vehicle movements) and the presence of two interchanges (with entering or leaving traffic flows).

However in the framework of the ASAP project it was necessary to concentrate on free flowing traffic, i.e. when the speed choice is not (or not too much) constrained by an external factor like a traffic jam, a work vehicle entering the work zone or even a fluidity problem at a motorway exit. A filtering of the data sets was therefore needed to focus on non-constrained speed data.

3.3.6.1 Aggregation of the data

The sensors deployed on site (i.e. Icoms Doppler radars and Wavetronix digital wave radars) provided individual vehicle data. In a first step, these data were aggregated on a 5 minutes time interval appropriate to show traffic flow and speed variations and the following variables calculated for the time interval:

- The Number of Vehicles detected;
- The Mean speed;
- The 85th Percentile Speed;
- The Standard Deviation;
- The Absolute Minimum speed recorded;



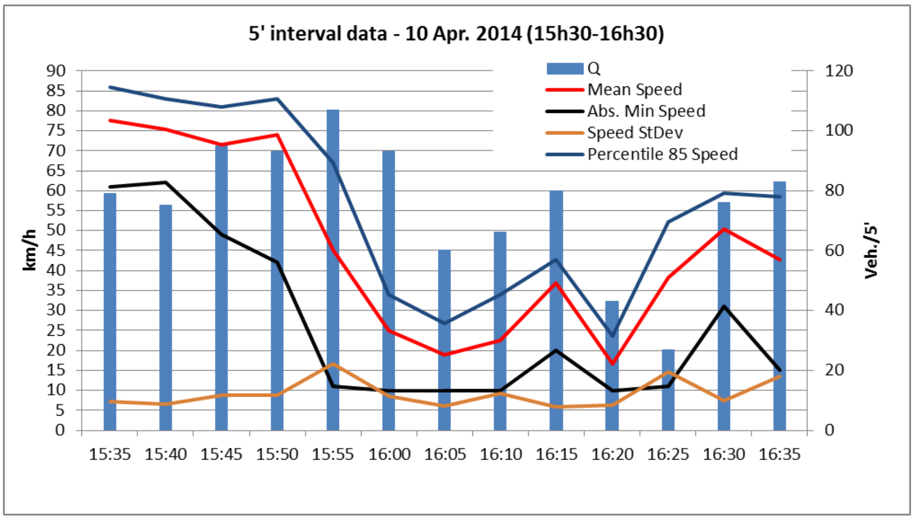


Figure 5: From Single vehicle Speed data to 5 minutes interval data: example from the A15/E42 site

The example here above (**Figure 5**) shows the initiation of a congestion event that starts around 15h50. The below graph demonstrates that events impacting strongly the traffic flow and speed can be identified through a detailed analysis of the 5 minutes interval data. Absolute traffic volume, mean speed, absolute minimum speed, standard deviation and traffic volume variation can be used complementarily to identify periods when the speed choice is constrained by an external factor and exclude them from the dataset. These variables have been used to filter all the datasets, as explained hereafter.

3.3.6.2 Description of the filtering process

Five individual "data quality warnings" have been developed to filter the data:

- *IQ TrafficFlow* is based on the principle that the traffic is not flowing freely anymore when the traffic volume is close to the lane capacity;
- *IQMeanSpeed* suggests that intervals with mean speeds much lower than the speed limit isn't coherent with a free flowing traffic condition;
- *IQ StDev* is based on the observation that the speed variance typically increases when a congestion starts or ends and remains a little bit higher during such periods as compared to free flowing traffic conditions (as showed on the graph above at 15h55 & 16h25);
- *IQ Min Speed* relies on the fact that when the traffic is congested, one (or more) vehicle(s) will travel at very low speed(s). A strong decrease of the Mean Speed often happens simultaneously, but not always.
- *IQ TrafficFlowVariation* relates to the fact that the traffic variation from one interval to the next one is usually higher when a congestion problem starts.

However these warnings must be used altogether because they are clearly complementary. For example, the standard deviation may increase when congestion starts or ends, but also during the night when the traffic volume is much lower and the speed differences between successive vehicles a little bit higher. The absolute minimum speed during the interval could be low not only because the traffic is globally impacted by a local event on along the work zone, but also because one single driver needs to brake strongly due to the local circumstances.

The five variables above were therefore used as "warnings" instead of immediate excluding criteria.

<u>Definition of thresholds for each "data quality warnings" and exclusion of doubtful data sets</u>

Based on a detailed analysis of the datasets a threshold has been defined for each variable (note that it may be slightly different from site to site as the traffic pattern and the prevailing local conditions may differ slightly) and used to generate warnings (as shown on the next table). In a second step the *warnings* were concatenated and color coded.

In a last step it has been decided to exclude all data intervals presenting at least two warnings (**Figure 6**). This was based on a very simple sensitivity analysis, showing what datasets would be excluded if two or three warnings would be used as criteria.

Day	Time	Mean Speed	Q	Abs. Min Speed	Speed StDev	Percentile 85 Speed		IQ TrafficFlow	IQ MeanSpeed	IQ StDev	IQ MinSpeed	IQ TrafficFlow Variation	Global IQ
4/10/2014	15:35	77,6	79	61,0	7,2	86,0							
4/10/2014	15:40	75,3	75	62,0	6,5	83,0							
4/10/2014	15:45	71,6	95	49,0	8,8	81,0							
4/10/2014	15:50	74,0	93	42,0	8,8	82,9					!		!
4/10/2014	15:55	45,1	107	11,0	16,6	67,0			!	!	!		!!!
4/10/2014	16:00	24,9	93	10,0	8,5	34,0			!		!		!!
4/10/2014	16:05	18,9	60	10,0	6,1	26,9			!		!	!	!!!
4/10/2014	16:10	22,6	66	10,0	9,1	34,0			!		!		!!
4/10/2014	16:15	36,9	80	20,0	5,8	42,9			!		!		!!
4/10/2014	16:20	16,6	43	10,0	6,4	23,6			!		!	!	!!!
4/10/2014	16:25	38,3	27	11,0	14,5	52,2			!		!	!	!!!
4/10/2014	16:30	50,4	76	31,0	7,5	59,5			!		!	!	!!!

Figure 6: Identification of doubtful data sets through the use of a set of “data quality warnings”

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3.4 *Description of the showcases*

3.4.1 Showcase in Czech Republic - D1 motorway, section Prague-Brno

3.4.1.1 Location and roadwork characteristics

Several detection systems, which collect data on traffic flow, have been installed on motorway D1 between Prague and Brno during its reconstruction.

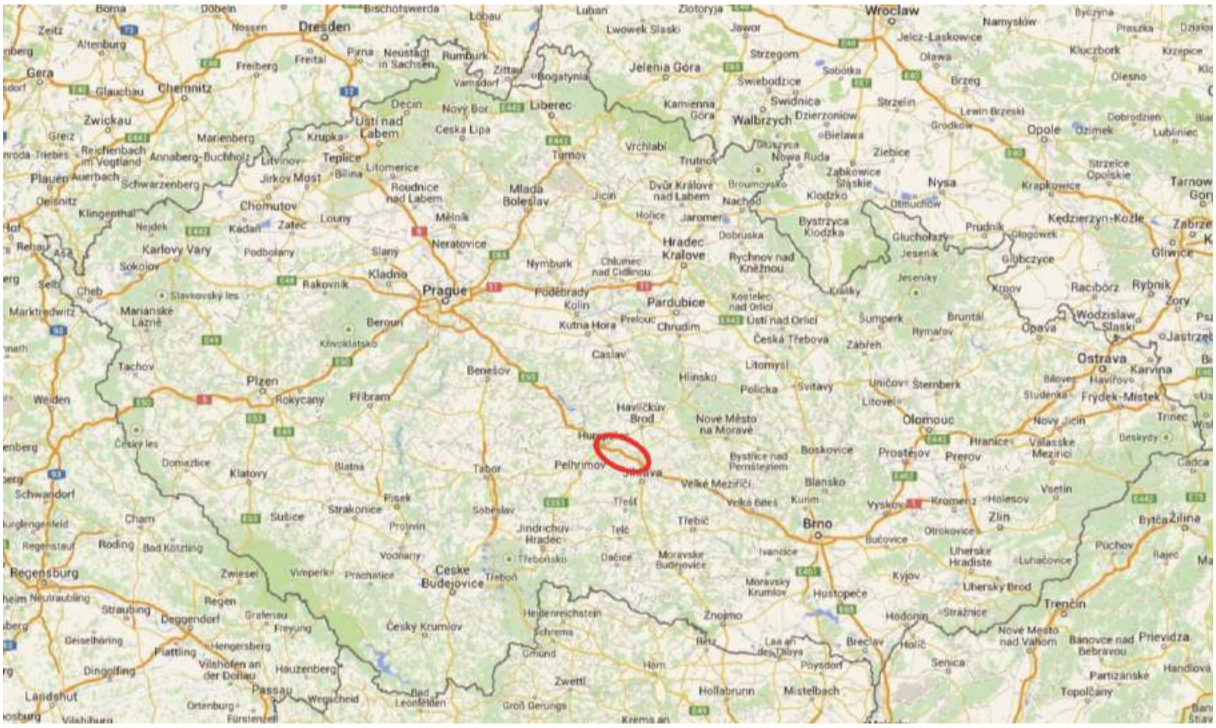


Figure 7: Location of the work zone along the D1 motorway

The D1 reconstruction has been the biggest scale reconstruction for the past decades. It included complete repair of selected sections: consolidation of subgrade, replacement of road pavement, repair of crash barriers, and extension of traffic lanes. 9 temporary traffic management situations in total were installed on the motorway in 2014. Within the ASAP project, the detection systems were installed along the road works between Jihlava and Větrný Jeníkov (kilometer 112 to 104; **Figure 7**).

Motorway D1 in area of showcase has two lanes in every direction, central reserve. The total width is 26,5 meters and pavement is made from concrete.

Figure 8: D1 motorway in the showcase area and sign informing drivers about the experimentation

Roadwork main characteristics

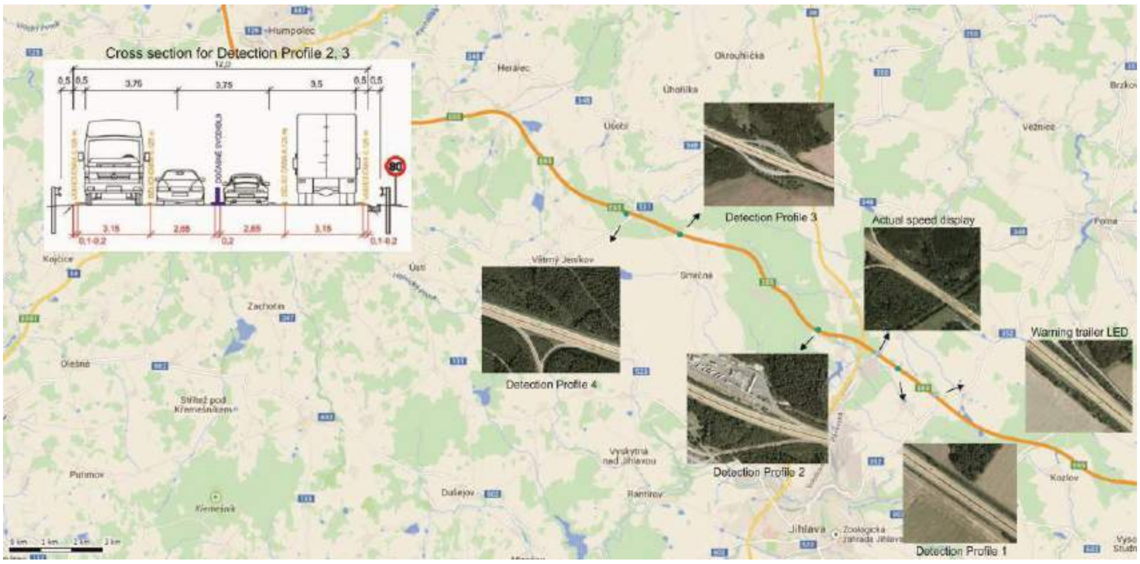


Figure 9: Road works cross section and location of the detectors

The road works on the above mentioned motorway section began in March 2014. The traffic was guided into the right traffic lane by a system 2+2 in the direction from Brno to Prague (**Figure 9**). The traffic flow directions were divided by a temporary crash barrier *Protec 100* (**Figure 10**).

Figure 10: View of the temporary crash barrier used to separate opposite traffic flows

The different widths of traffic lanes in the direction from Prague to Brno were as follows:

- Km 104.372 – 111.580: 3.15m for slow vehicles
  2.65m for fast vehicles
- Km 111.960 – 112.000: 2.50m for slow vehicles
  2.90m for fast vehicles
- Km 112.120 – 113.403: 2.50m for slow vehicles
  3.05m for fast vehicles
- Km 113.590 – 113.670: 2.50m for slow vehicles
  3.25m for fast vehicles

The mentioned road works were in progress in the left traffic lane roughly until the end of July.

Signing and equipment (base/reference situation)

In the direction of Brno is 104,252 km transferred right in two auxiliary lanes on width of 2.5 meters to 3.15 meters upstream lane, and thus continues to 113.403 km, where both lanes transferred back into the right lane. To the left of the auxiliary lane is banned from vehicles whose width exceeds the instantaneous 2.2 m. The speed limit is reduced to 80 km / h, with the exception of sections before crossing the central reserve of the belt where the speed limit is reduced to 60 km / h.

At Jihlava (Exit 112) was temporarily closed direction to Brno. Diversion route goes along the highway D1 at Větrný Jenikov (Exit 104), where the right "turn" back to Brno. A rest Pávov (right) will be for the duration of this phase is concluded.

In the direction of the city is 113,820 km in traffic restricted in two auxiliary lane width of 2.5 meters by 3.15 meters to the right of the highway and thus leads to km 104.120, where traffic restrictions ends. To the left of the auxiliary lane is banned from vehicles whose width exceeds the instantaneous 2.2 m. The speed limit is reduced to 80 km/h. It will allow access road to the Jihlava (EXIT 112) and rest area Pávov (left).

Road users' information (Before/During the works)

The Czech Road Directorate informs the general public about the current delay that is caused due to the modernization of the most important road in the Czech Republic – the D1 motorway. A traffic portal[6] is managed and operated by the company CROSS Zlín, a.s. within the project "The modernization of the D1 motorway" by Czech Road and Motorway Directorate (**Figure 11**). There are updated and historical data of delays within the individual sections of modernized parts of the D1 motorway on the portal, which brings the current traffic conditions to all drivers of the D1 motorway online (also via mobile application). Information about the delay is updated each five minutes in order to guarantee the sufficient amount of data to calculate the actual delay. In case of lower traffic (mostly at night), this interval is extended to 20 minutes maximally for these reasons.

[6] www.uzavery-d1.cz; Information about the modernization is also available on www.novad1.cz and www.dopravniinfo.cz.

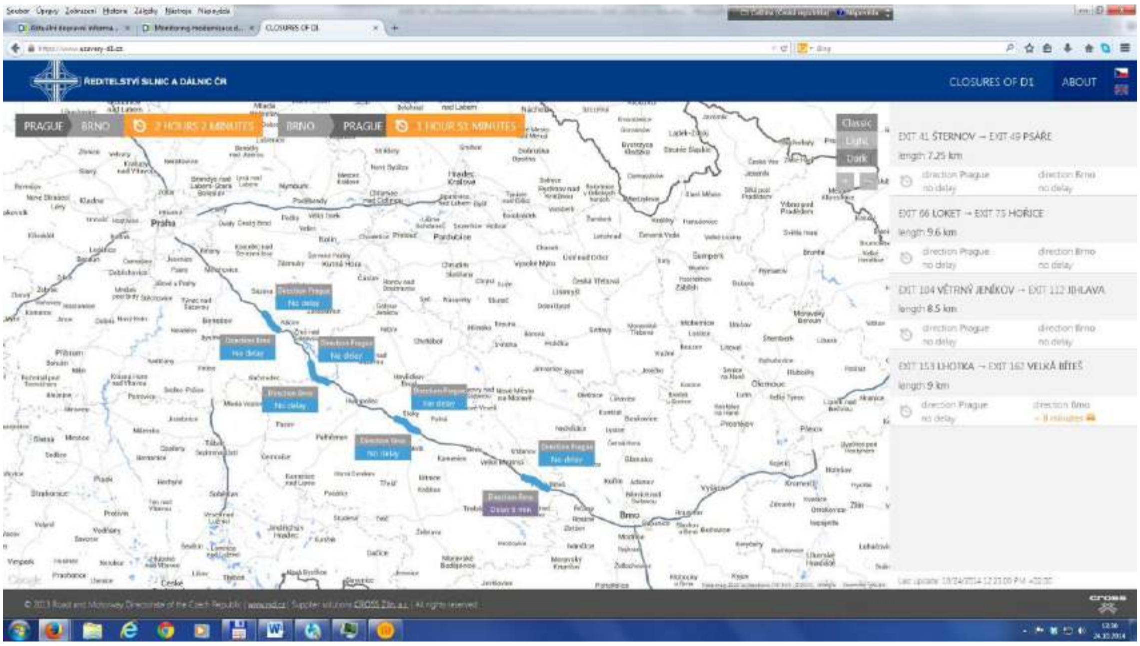


Figure 11: Website on modernization of the D1 motorway

3.4.1.2 Speed management measures and Monitoring equipment

As already mentioned detection systems were installed along the work zone between Jihlava and Větrný Jeníkov (km 104 to 114). The measures mentioned later in this chapter were identified as suitable in order to verify their effectiveness in real conditions. The test aims to verify these measures and to support tools for monitoring vehicle speeds in front of and within traffic restrictions.

The testing system was divided into two separate independent levels:

1. Detection subsystem (or monitoring equipment) for the collection of traffic data from detection technologies;
2. Installation of “actors” and change of displaying – road signing and marking, variable road signs, traffic police departments (also called Speed management measures).

Monitoring equipment

Different types of traffic detectors were used in order to collect traffic data. The detectors were placed while taking into account the need to collect information on the impact of individual traffic measures on traffic flow behavior and on individual drivers (**Figure 12**). The sensors were placed in front of the traffic restriction site as well as inside of the work zone. The detection part of the system was formed by Wavetronix devices. As demonstrated within the ViaZONE project this detection system is able to collect data in the mode “vehicle to vehicle” while distinguishing individual categories. It is easily portable and its calibration is simple.

Information on data collection

- *Installation of detectors:* 21 May 2014
- *Disassembly of detectors:* 24 July 2014
- *Setting of detectors regarding the classification of vehicles (4 vehicle classes by length):*
    - 0 – 5.5 m: personal vehicles
    - 5.5 – 8 m: vans

- 8 – 12.5 m: heavy vehicles
- 12.5 m and more: semitrailer trucks

- *Setting of detectors regarding the collection of traffic data:*

Vehicle to vehicle mode was used with transfer of data packets in regular intervals. In the case of no throughput of the network, individual packets were stored in the computer memory and sent once the network was available. Unfortunately, GSM technology failure occurred within the test around the station 2 near a petrol station and it was impossible to use the data on events. Therefore, the evaluations use the interval data. The data on events include the following information:

- Lane: number of traffic lane (while No. 0 is always the closest to detector)
- Length: vehicle length in metres
- (KPH): data on vehicle speed in km/h
- Class: vehicle class, vehicle is classified by its length
- Range: vehicle distance from radar
- Sensor Time: date and time in three decimal points of a second

Interval data include the following information:

- Name: number of traffic lane
- Volume: traffic volume – number of vehicle in a given interval
- Occupancy (%): traffic lane occupancy rate (in radar view angle)
- Speed (KPH): traffic flow speed in an interval
- 85%Speed: 85th percentile of speed in an interval
- Class count: number of vehicles in individual set classes

Installation of traffic detectors

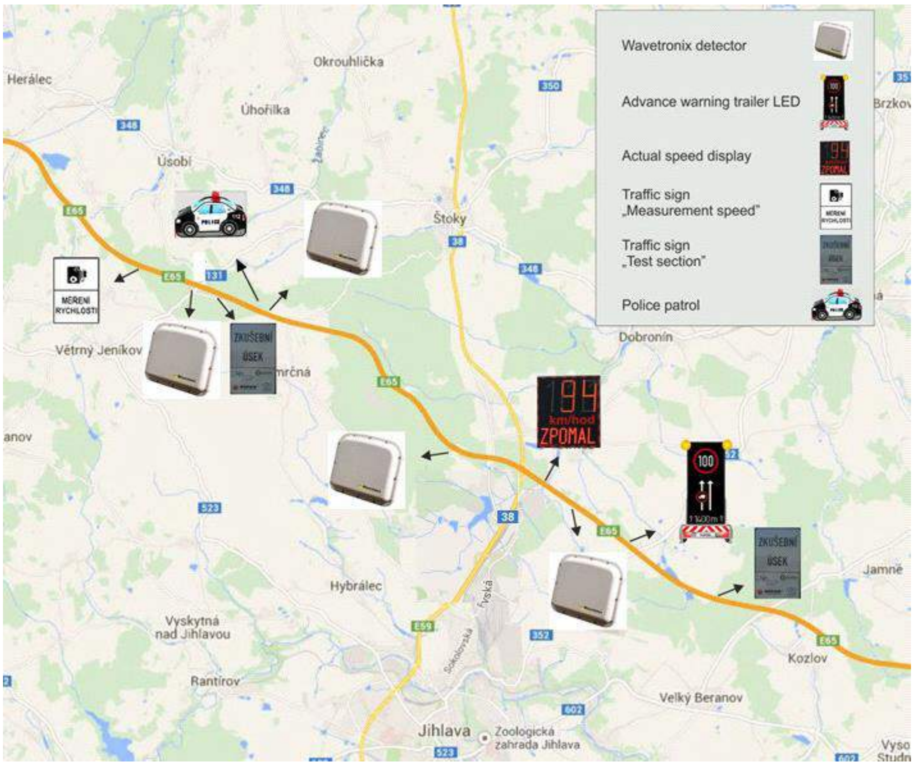


Figure 12: Respective location of the detectors and successive speed management measures

Detection profile 1 – STATION 1

The installation was performed on a road sign (**Figure 13**). A battery, which was placed in an anti-vandalism box, was used for the power supply to the detector. The box was fixed to the road sign with a chain. For the installation of the detector, the vehicle was parked in the hard shoulder, while the biggest part of the vehicle was parked on grass next to the hard shoulder. The vehicle was equipped with a beacon.

Kilometre: 114.1 (distance from the beginning of the transition area: 300 m)

Monitored traffic lanes:

- 0 – Right traffic lane Prague bound (350 m in front of the transition area)
- 1 – Left traffic lane Prague bound (350 m in front of the transition area)
- 2 - Left traffic lane Brno bound (350 m behind the transition area)
- 3 - Right traffic lane Brno bound

GPS localization: 49.444011, 15.628021

Figure 13: Overview of the detection site n°1

Detection profile 2 – STATION 2

The installation was performed on an aluminium post of approx. height of 550 cm. the detector was installed behind the crash barriers (**Figure 14**). The assumed connection to SOS-DIS system with power supply was not conducted, since this system was out of order during its upgrade, therefore alternative power supply from the accumulator needed to be used.

Kilometre: 111.3 (distance from the transition area bottleneck 2100 m)

- 0 – Right traffic lane Prague bound
- 1 – Left traffic lane Prague bound

GPS localization: 49.454748, 15.593362

Figure 14: Overview of the detection site n°2

Detection profile 3 – STATION 3

The installation was performed on an aluminium post of approx. height of 600 cm. The installation was performed behind the crash barrier and the vehicle was parked on an unused parking place, which can be reached by an access from the traffic restricted site Prague bound (**Figure 15**). The access to the “parking place” was protected by guiding boards, between which a vehicle can pass. The assumed power supply from SOS-DIS system was not conducted for the above mentioned reason. The system was supplied from an alternative accumulator power supply.

Kilometre: 105.5 (distance from the transition area: 1.3 km)

- 0 – Right traffic lane Prague bound
- 1 – Left traffic lane Prague bound
- 2 - Left traffic lane Brno bound
- 3 - Right traffic lane Brno bound

GPS localization: 49.489060, 15.507179

Figure 15: Overview of the detection site n°3 and installation of the Wavetronix detector

Detection profile 4 – STATION 4

The installation was performed on an aluminium post of approx. height of 600 cm. The installation was performed behind the crash barrier and the vehicle was parked on a grass area near an exit (exit Větrný Jeníkov) off the motorway (**Figure 16**). The power supply was conducted from SOS-DIS system.

Kilometre: 103.7 (distance from the transition area: 500 m)

- 0 – Right traffic lane Brno bound (350 m in front of the transition area)
- 1 – Left traffic lane Brno bound (350 m in front of the transition area)
- 2 - Left traffic lane Prague bound (350 m behind the transition area)
- 3 - Right traffic lane Prague bound

GPS localization: 49.489060, 15.507179

Figure 16: Wavetronix detector as installed on section 4

Speed management measures (or "Actors")

Different types of actors were used in the test. The aim was to verify the hypothesis that individual active elements on the infrastructure have an impact on the behaviour of traffic flows. The following actors were used in the test:

- Information trailer LED
- Advance warning trailer LED
- Actual speed display
- Mobile metal sign "SPEED MEASUREMENT"
- Presence of POLICE

a. Information trailer LED

Information trailer LED is the most common mobile variable road sign in the Czech Republic. It is currently used as a mobile information portal, which is usually placed approx. 5-6 km in front of a traffic restriction zone during the upgrade of D1. Within the pilot testing of ASAP, this information trailer was used for informing drivers of speeding (**Figure 17**). The information trailer was lent by ELTODO, a.s. (www.eltodo.cz)

Technical parameters:

Information panel:	dimensions: 1 900 x 2 500 mm, beam angle B4, bend 3°
Chassis:	two-axle, width 2 500 mm, length 3 000 mm, maximum load 2 500 kg
Power supply:	from mains 230 V AC or diesel-generator + battery durability 340 h
Communication:	Ethernet metallic / optics, GPRS, WiFi

Location of information trailer LED

Kilometre:	104.7km
GPS localization:	49.487546, 15.514719
Main impact on traffic data:	Station 3, BRNO bound
Secondary impact on traffic data:	Station 4, BRNO bound (in front of the system)
Distance from Station 3:	800 m

Schedule for installation and testing

Testing was divided into two display schemes:

1. Display scheme No. 1 – displaying speed limit with a sign B20a “80” in case of speeding. Simultaneously, a sign “ZPOMAL”, (it means SLOW DOWN) is displayed.
2. Display scheme No. 2 – displaying current speed of speeding vehicles including a sign “ZPOMAL”

Timing

- Date and time of installation: 5 June 2014, 14:00 a.m.
- Display scheme No. 1 – Beginning 5 June 2014, 14:00
End 20 June 2014, 7:00
- Display scheme No. 2 – Beginning 20 June 2014, 7:00
End 30 June 2014, 12:00

Figure 17: Overview of the information trailer used in the work zone

b. Advance warning trailer LED

Advance warning trailer LED is used as a replacement of metal advance warning devices. It is possible to use the device for the purposes of variable message signs under condition of meeting road safety requirements (installation behind crash barriers, etc.).

It is designed to reduce speeds in hazardous road sections, to warn drivers of hazards, in case of road accidents, under aggravated road conditions, in congestions, etc., for motorway and dual carriageway repairs and closures. Within the pilot testing of ASAP, this information trailer was used for enhancing road signing in front of the traffic restrictions (**Figure 18**). In addition, two display schemes were used. The advance warning trailer LED was lent by ELTODO, a.s. (www.eltodo.cz)

Technical parameters

- Display panel: full matrix black and white, dimensions 1534 x 2800 mm with beam angle B4 (in accordance with EN 12966-1)
- Chassis: one-axle, width 1980 mm, length 2 930 mm, maximum load 750 kg
- Power supply system: from mains 230V AC + battery durability 48 h
- Data communication: Ethernet /RS422/RS485/RS232/ GPRS, WiFi

Location of advance warning trailer LED

- Kilometre: 115.4 km
- GPS localization: 49.435977, 15.644577
- Main impact on traffic data: Station 1, Prague bound
- Secondary impact on traffic data: Station 2, Prague bound
- Distance from Station 1: 1300 m

Figure 18: Deployment of the LED advance warning trailer

Schedule of installation and testing

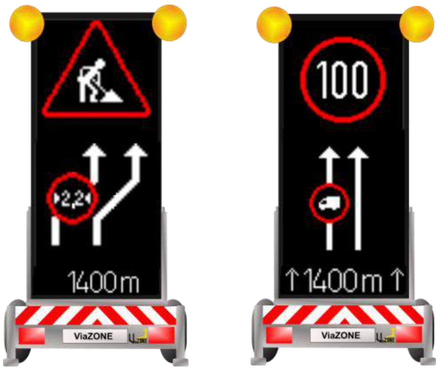
Testing was divided into two display schemes:

1. Display scheme No. 1 – displaying road works sign on upper display and on the bottom sign was used arrangement lanes
2. Display scheme No. 2 – displaying speed sign “100” on upper display and on the bottom was used restriction on the carriageway sign

- Date and time of installation: 13 June 2014, 7:00 a.m.
- Display scheme No. 1 – Beginning 13 June 2014, 7:00
  End 20 June 2014, 7:00
- Display scheme No. 2 – Beginning 20 June 2014, 7:00
  End 27 June 2014, 7:30
- Display scheme No. 2 (continuously without switching off)
  Beginning 27 June 2014, 7:30
  End 30 June 2014, 10:00

Timing (when the system was on)

- 7:00 – 9:00
- 11:00 – 12:00
- 15:00 – 17:00
- 21:00 – 22:00



Scheme No. 1 on the left and scheme No. 2 on the right

c. Actual speed display

The used actual speed display is a common feature in towns and villages where speeding occurs frequently. The speed display is the bestselling system in the Czech Republic, and based on the independent assessments of the Police of the Czech Republic, this device has the biggest effect on traffic speed at these hazardous localities in towns and villages in the Czech Republic. The device was supplied from accumulators and stayed at the locality for 14 days. The accumulators had to be replaced every 4 days (**Figure 19**).

The device was lent by EMPEMONT, s.r.o.

Technical parameters:

- Display panel: LED, amber 590 nm, height of digits 380 mm + sign " ZPOMAL" with the height of digits 180 mm
- Construction: stainless steel (anti-vandalism design)
- Dimensions: 780 x 890 mm
- Radar: reach longer than 300 m, resolution 0.1 km/h

Location of Actual speed display:

- Kilometre: 113.0 km
- GPS localization: 49.448886, 15.617141
- Main impact on traffic data: Station 2, Prague bound
- Secondary impact on traffic data: Station 3, Prague bound
- Distance from Station 2: 1700 m

Schedule

Date and time of installation:
- 10 July 2014, 12:00 Installation;
- 26 July 2014, 12:00 System uninstalled.

Figure 19: Speed display (*94km/h – Reduce your speed*)

d. Steel structure with a sign "MĚŘENÍ RYCHLOSTI" (Speed camera present; Figure 20)

Location

- Kilometre: 102.6 km
- GPS localization: 49.495680, 15.483240
- Main impact on traffic data: Station 4, Brno bound
- Secondary impact on traffic data: Station 3, Brno bound
- Distance from Station 4: 1100 m

Schedule

Date and time of installation:

- 19 July 2014, 16:00 Installation;
- 26July 2014, 12:00 System uninstalled.

Figure 20: Watch-out sign (*speed camera present*)

e. Cooperation with Police of the Czech Republic

The cooperation with traffic police in Velký Beranov was established at the very beginning. The communication was conducted with npor. Mgr. David Jirák, the head of the centre. It was agreed that a police patrol will regularly be present at specific places.

Police patrol times and places

- Patrolling time: 9:30 – 10:30 every day
- Place
  - Kilometre: 105.5 km
  - GPS localization: 49.4838728N, 15.5282753E
  - Main impact on traffic data: Station 3, Prague and Brno bound
  - Secondary impact on traffic data: Station 4, Prague bound
  - Distance from Station 3: same place (100m between detector and Police patrol stop area)

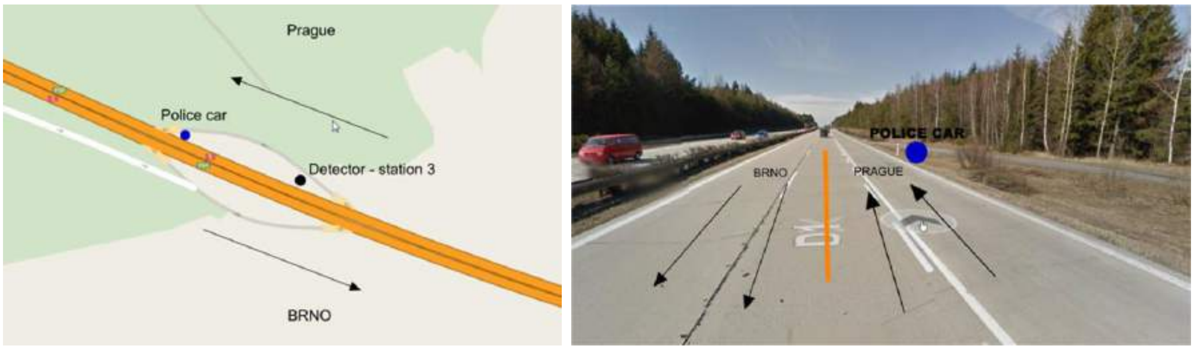


Figure 21: Respective location of the Police car and detector n°3

3.4.1.3 Test scheme and available data

Figure 22 schematically synthesizes the location of the detectors and speed management measures tested during the showcase. More detailed schemes are provided in appendix 1.

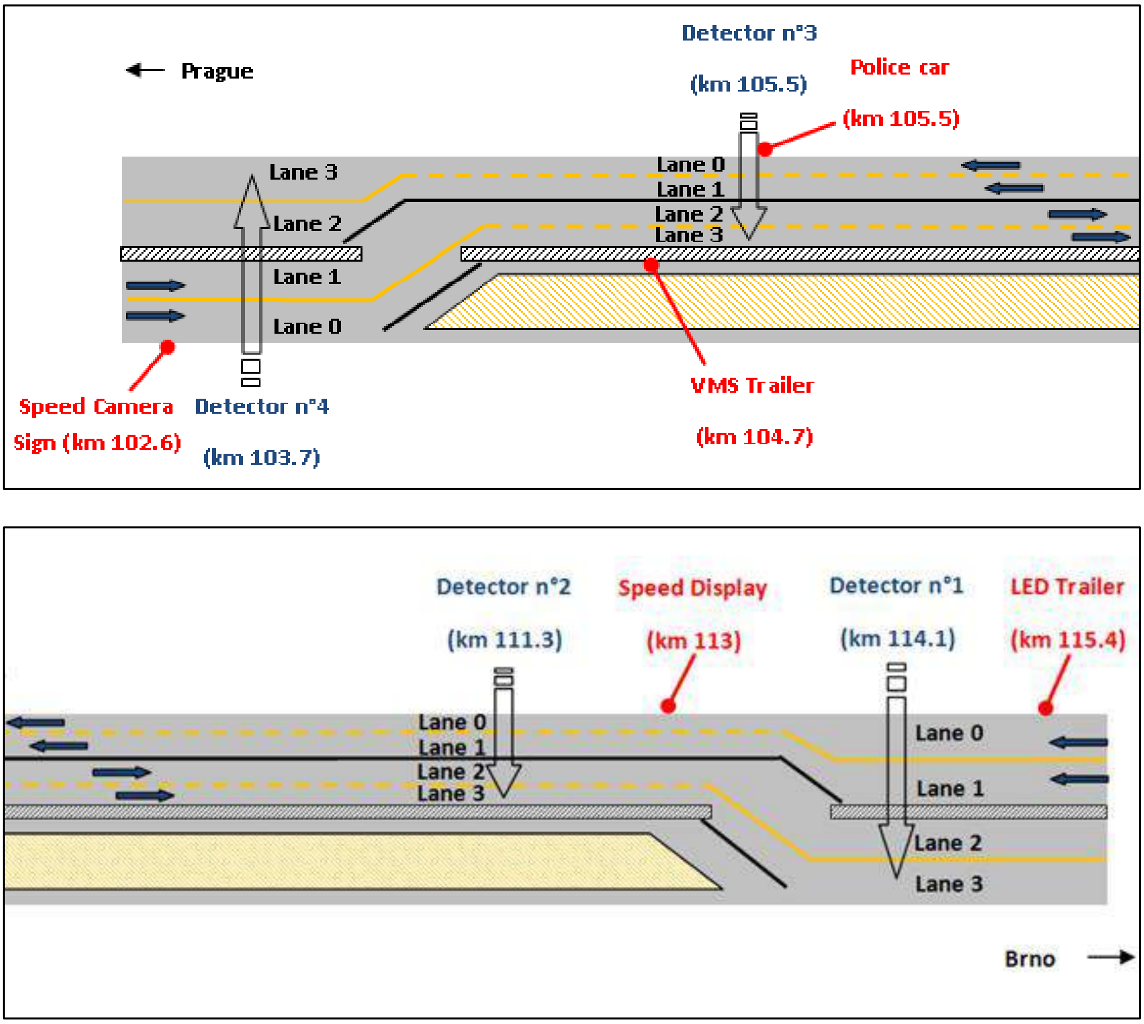


Figure 22: D1 motorway – Showcase scheme (the lane numbering depends on the detector location)

Table 2 also resumes the activation periods of the various measures that have been implemented on site, as well as identifies the detectors that are primarily impacted by the deployment of each measure and for which the data analysis has been performed.

Table 2: D1 motorway (CZ) – Activation period of the tested measures and influence on detectors

					Detector n°1	Detector n°2	Detector n°3	Detector n°4
					dir 1 Prague (Lane 0, Lane 1) / dir 2 Brno (Lane 2, Lane 3)	dir 1 Prague (Lane 0, Lane 1) / dir 2 Brno (no data)	dir 1 Prague (Lane 0, Lane 1) / dir 2 Brno (Lane 2, Lane 3)	dir 1 Brno (Lane 0, Lane 1) / dir 2 Prague (Lane 2, Lane 3)
ACTORS			**from**	**to**	**speed limit 100 km/h**	**speed limit 80 km/h**	**speed limit 80 km/h**	**speed limit 100 km/h**
VMS trailer	signaling scheme A	**1 A**	5.6. 2014 14:00	20.6. 2014 7:00			●	○
	signaling scheme B	**1 B**	20.6. 2014 7:00	30.6. 2014 12:00				
LED trailer	signaling scheme A	**2 A**	13.6. 2014 7:00	20.6. 2014 7:00	●	○		
	signaling scheme B	**2 B**	20.6. 2014 7:00	30.6. 2014 10:00				
speed display		**3**	10.7. 2014 12:00	26.7. 2014 12:00		●	○	
speed camera sign		**4**	19.7. 2014 16:00	26.7. 2014 12:00			○	●
police car (every day between 9:30 and 10:30)		**5**	5.6. 2014 (e.d)	26.7. 2014 (e.d)			●	○

● main influence
○ secondary influence

analysed situation
omitted situation

.

3.4.2 Showcase in Belgium – Motorway A15/E42, section Daussoulx-Sambreville

3.4.2.1 Location and roadwork characteristics

Motorway A15/E42- Location and characteristics

The A15/E42 is a main Belgian motorway crossing the country (East-West). It is an essential transport axe for national traffic and an important corridor for European traffic as it connect the Western German landers with the Eastern French regions (**Figure 23**). In 2010 the annual average daily traffic along the section Daussoulx-Sambreville was around 65.000 vehicles (both directions). During the road works around 13.000 to 14.000 vehicles per day have been detected on each lane by the monitoring devices (26.000 to 28.000 in the RW direction).

Figure 23: Location of the road works along the A15/E42 motorway (red circle)

Figure 24: Details on the location of the road works (red line) and the connecting road network

As shown on (**Figure 24**), the road works were carried out close to the interchange between the A15/E42 and the A4/E411 motorway, both being main motorways of the Belgian network.

The A15/E42 motorway built in the early seventies and composed of 2 lanes (+ a hard shoulder) in each direction is progressively upgraded to 3 lanes (**Figure 25**). The upgrade works (additional lane) between Sambreville and Daussoulx has been achieved in 2013. The 2014 works consist in the same type of operation on the other side of the motorway; giving a 20 km long road work between Daussoulx (around kp 49) and Sambreville (around kp 69) to be executed in 2014 between April and the summer months.

Figure 25: View of the A15/E42 (between Daussoulx & Sambreville) before the 2014 works (additional lane to be built on the left side and new pavement to be laid across all the lanes)

Roadwork main characteristics

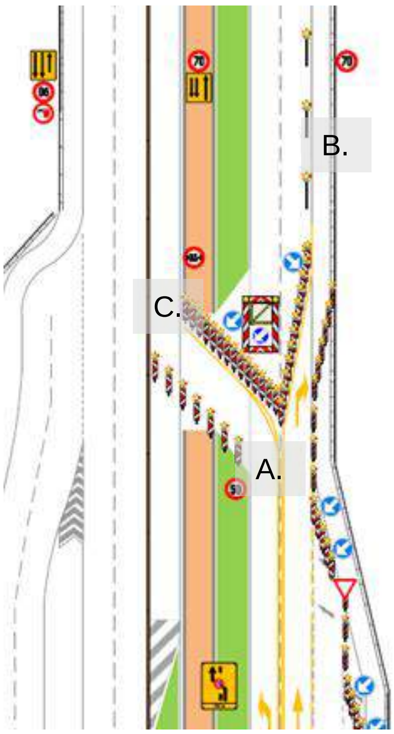
In 2014 the road works were only executed on the left side of the motorway along the Daussoulx – Sambreville section; they were scheduled around three consecutive stages:

- Stage 1: Quick reconditioning of the hard shoulder to later temporarily support the deviated traffic ;
- Stage 2: Construction of the additional (left) lane, punctual renovation of the existing concrete pavement (existing left and right lanes), reconstruction of the bridge expansion joints and resurfacing the existing left lane by a new bituminous layer;
- Stage 3: Rehabilitation of the hard shoulder, continuing work on the bridge expansion joints and resurfacing of the right and hard shoulder lane by a new bituminous layer, renewal of road signs and upgrade of the lateral safety barriers.

All the speed monitoring actions carried out for the ASAP project happened during the second stage. During this stage, the existing right and left lanes were both closed to the normal traffic to support the traffic of road work equipment, to ease the access/ exit of road work vehicle into/from the work area, to provide space for the emergency services (in case of an accident) and finally to provide a larger lateral safety distance for the road workers. As shown on following pictures, the road work area was primarily delimited by portable road work panels and locally (e.g. work closer to the traffic, on bridges, etc.) by a temporary safety barrier.

To keep the motorway capacity as high as possible, the temporary traffic management consisted in keeping two lanes open in each direction (

Figure 26). During the second stage, the traffic has been deviated to the hard shoulder lane (around 4m width; giving access to the three interchanges and the two rest areas located along the work zone) and to a contraflow lane (around 3.25m width) separated to the opposite traffic flow by a continuous safety barrier. On both lanes, the speed along the work zone was limited to 70 km/h. The speed limit in the transition area (50m long opening in the central reserve) was 50km/h.



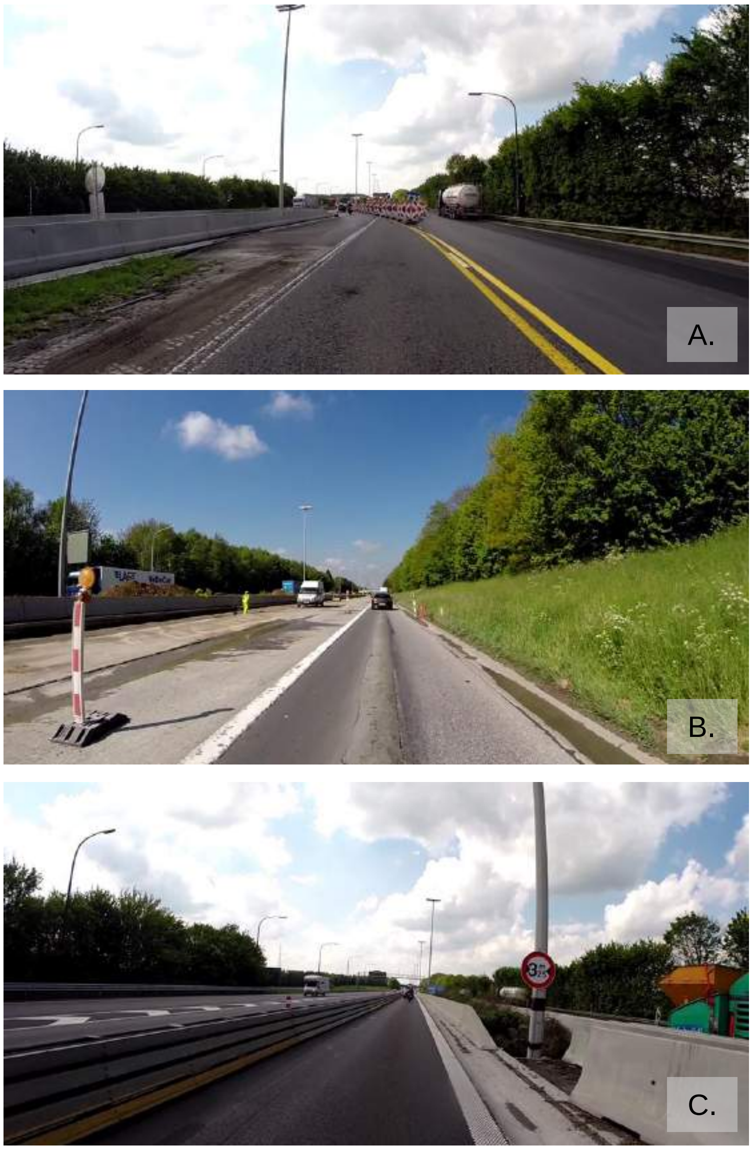


Figure 26: Temporary traffic management around the transition area (work area = green area) during the second stage of the works

A: transition area

B: Hard shoulder lane

C: Contraflow lane

Signing and equipment (base/reference situation)

Table 3 presents the temporary road signs installed along the advance warning area as well as the speed limit scheme. In this list some road signs are mandatory (to comply with the federal or regional regulations), other are used to inform drivers about the road work layout or about the accessible exits along the work zone.

Table 3: A15/E42 road works – Signing and equipment

KP (km)	Distance from a reference Point	**Road sign or marking** (pictures taken on site)	Type
42.95	- 5250m		Road user information about lane layout
45.8	- 2400m		Road user warning – Likely queuing - <u>Mandatory</u>
46.7	- 1500m		Road user information about lane layout - <u>Mandatory</u>
46.8	- 1400m		Upcoming 90km/h speed limit sign - <u>Mandatory</u>
46.9	- 1300m		Road user information about lane layout & exits

47.1	- 1100m		90km/h speed limit sign - Mandatory
47.2	- 1000m		Road user information about lane layout - Mandatory
47.4	- 800m		Road user information about lane layout & exits
47.7	- 500m		70km/h speed limit sign – Mandatory
47.95	- 150m		Road user information about lane layout - Mandatory
48.05	- 50m		Road user information about possible Speed control
48.1	- 100m		70km/h speed limit sign - Mandatory

48.2	Reference Point		Road user warning - <u>Mandatory</u>
48.25	- 1050m		70km/h speed limit sign
48.5	- 800m		Road user information about lane layout - Marking
49.0	- 300m		70km/h Speed limit sign - <u>Mandatory</u>
49.1	- 200m		Road user information about lane layout
49.2	- 100m		Road user information about lane layout - <u>Mandatory</u>
49.25	- 50m		50km/h Speed limit sign - <u>Mandatory</u>

49.3	Crossover start		Crossover and buffer zone

These signs were installed from April 2014 until the end of the road works (end of the summer months). Therefore pictures on **Table 3** show the base/reference situation mentioned hereafter, together with some variable message signs (fixed or mobile) as presented in the next chapter.

Road users information (Before/During the works)

These road works being executed on a major motorway - i.e. supporting high national and international traffic volumes – the road authority organized a communication campaign through the media. Regular updates were posted on the Traffic Center website.

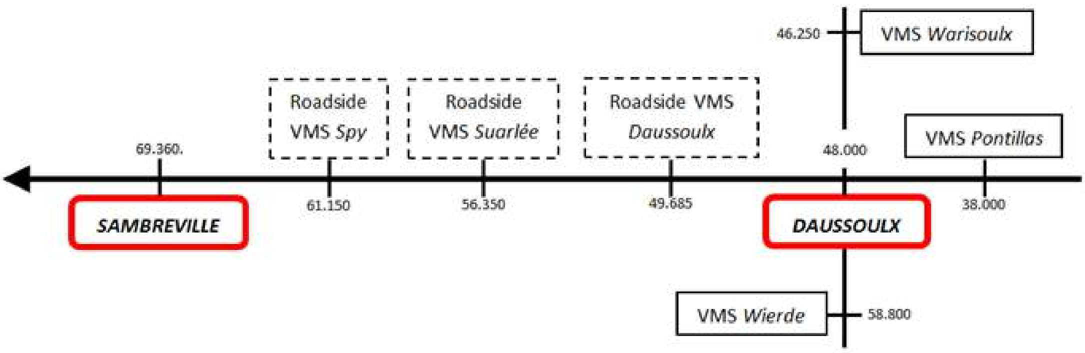
The variable message signs (VMS) available along and in the vicinity of the road work section were activated (**Figure 27**). As explained hereafter, some VMS trailers were also used in addition to the existing fixed devices.

Communication to the road users through the media

The first official information was released on the 4th of March 2014 (around 3 weeks before the start of the road works) to the media and through the Traffic Center website (http://trafiroutes.wallonie.be). It informed the drivers about the location, the duration and the objectives of the road works. The speed limit regime was also mentioned in the release, as well as the fact that the traffic Police will regularly organize speed controls.

Roadside systems

Fixed Variable Message Signs



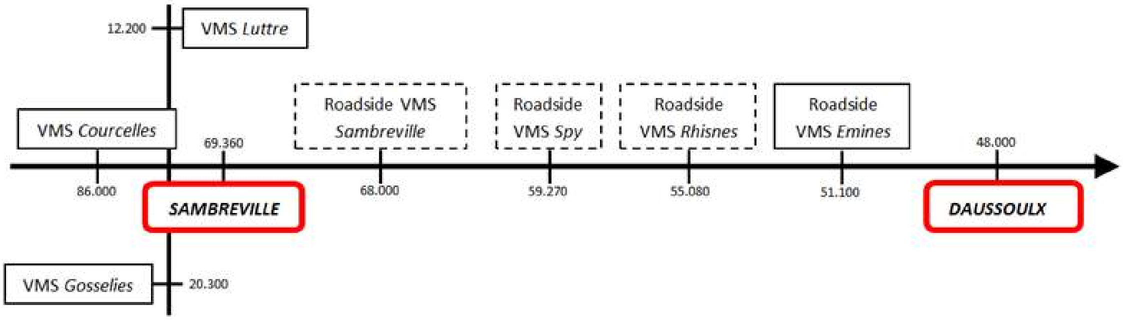


Figure 27: Fixed variable message signs used along and in the vicinity of the work zone

A preventive signing campaign started around one week before the works started. This first step was followed by the "effective" signing campaign that ended with the road works (**Figure 28**).

Preventive signing campaign	**Effective signing campaign**		
e.g. on VMS *Pontillas*	e.g. on VMS *Pontillas*	e.g. on Road side VMS *Spy*	
			
LE 28/3	A 10 KM	FIN	FIN
TRAVAUX A 10 KM	SUR 22 KM	A 9 KM	A 9 KM
SUR 22 KM	PRUDENCE		

Figure 28: Example of preventive and effective signing through the fixed variable message signs

Additional Variable Message Signs (on trailers)

Some trailers equipped with VMS were also installed along the A15/E42 and along the intersecting A4/E411 motorway (as the road works were carried out close to the interchange between both motorways). Trailers were mainly installed upstream of the work zone to inform drivers about a possible rerouting, e.g. in case of a risk of traffic disruption along the work zone (**Table 4**).

Table 4: Mobile VMS trailers used around the A15/E42 road works

- A15/E42 – To Sambreville - KP 42.15 for Road user information about the road works, incidents and rerouting;

- A15/E42 – To Sambreville - KP 47.95 (close to the transition area) for Traffic management ;

- A15/E42 – To Daussoulx - KP 77.5 for Road user information about the road works, incidents and rerouting;

- A15/E42 – To Daussoulx - KP 71.8 (close to the transition area) for Road user information about the road works, incidents and rerouting;

- A4/E411 – To Daussoulx-Sambreville; KP 41 for Traffic and rerouting management.

These VMS trailers were primarily used where no fixed VMS were available.

3.4.2.2 Speed management measures and Monitoring equipment

As already mentioned the A15/E42 showcase carried out BRRC being not scheduled from the initial stage of the project was less embedded in the road work project than on the Czech

D1 and therefore mainly consisted in a speed monitoring campaign. The A15/E42 road work circumstances and the speed management measures scheduled on these sites were supposed to provide an opportunity to complement the scenarios tested on the Czech site.

Speed management measures

Since some years, automatic speed cameras (**Figure 29**) are deployed on major road works carried out along Belgian motorways. These (semi-mobile) systems are installed for one or several weeks (consecutive or not) and control all the passing traffic. Such a system has been in operation for several weeks along the A15/E42, as shown on the table below (chapter 3.4.3.3).

Figure 29: Example of an installation of an automated Speed Camera (s*ource: www.securoad.be)*

Other devices identified as promising speed management measures were also scheduled on this road work site; i.e. portable speed displays and a trailer with a display of speed and car plate number. Unfortunately these systems, property of the road authority, were finally not available during the speed monitoring campaign. Therefore the only measure tested on site, in addition to the signing, equipment and VMS mentioned in the previous chapter, was the automatic speed camera.

Monitoring equipment

Various systems were installed along the road works with the intention to monitor the traffic speed at several locations. The location of the devices was decided based on the possible locations for the speed management measures; i.e. the automatic speed camera, the portable speed displays and the trailer with speed/car plate number display. Unfortunately the two latter were finally not available for the testing.

The following two types of device were used to monitor the speed along the road work:

- A multilane *Wavetronix Smartsensor HD* (digital wave radar) owned and operated by BRRC;

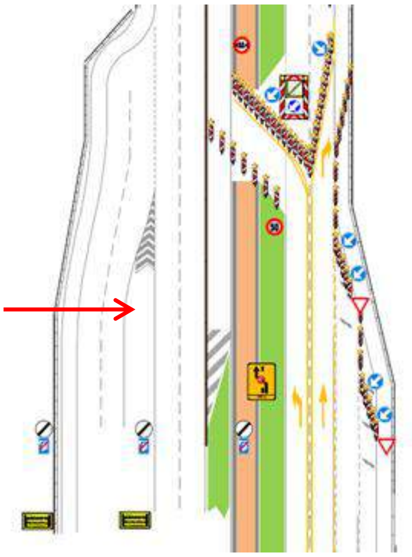


Figure 30: Wavetronix fixed on a gantry at KM 49,1 (200m before crossing the central reserve)

Being specifically acquired for the ASAP project, the A15/E42 site has been the first test site for the BRRC Wavetronix sensor and various problems related to the installation conditions and the power consumption have arisen.

Problems were solved but caused unfortunate gaps in the data sets from this device. Available data sets are synthesized in the table below (chapter 3.4.2.3).

- Three portable (single lane) Doppler radars (*type TMS-SA from Icoms Detection*) owned and operated by the Walloon road authority.

  These devices were installed all along the monitoring period. The only gaps in the data sets correspond to the time necessary to reload the batteries.

TMS-SA along Hard-shoulder PK 57.35

TMS-SA along Hard-shoulder PK 59.35

TMS-SA along Contraflow PK 53.3

Figure 31: Location of portable (single lane) Doppler radars

Equipment location scheme

The following scheme (**Figure 32**) synthesizes the devices installed on site and their location.

These locations were decided in an early stage based on the idea that portable speed displays and trailers with a display of speed and car plate number would be available for testing. Speed monitoring devices were supposed to be located 300m after these displays or trailers for which suitable locations were identified. Unfortunately these systems, property of the road authority, were finally not available during the speed monitoring campaign

Figure 32: A15/E42 Road works - Equipment location scheme

As described in the next chapter, some devices were not installed or operational on site all along the monitoring campaign.

3.4.2.3 Test scheme and available data

The test periods presented in **Table 5** have been defined based on the periods the automatic speed camera has been deployed on site and on the data available from the speed monitoring devices. During periods 1 and 3 an automatic speed camera was installed on KP 48,25 (in the 70 km/h zone and around 1 km before the crossing of the central reserve) and on KP55,6 (along the work zone and around 6 km after the transition area) respectively.

Table 5: A15/E42 Road works - Test scheme and available data

Test Periods	Data
Period 1: 08/04 to 29/04/2014 (weeks 1 to 3) Speed Management Measure: Automatic speed camera Location: KP48,25 (1 km upstream the transition area) 	- 08/04 to 23/04 & 25/04 to 29/04: 3 Doppler radars: o KP57,35 & KP59,35 (right side; veh./veh. speeds); o KP53,30 (left side; veh./veh. speeds)
Period 2: 29/04 to 06/05/2014 (week 4) Measure: Base/Reference situation Location: /	- 29/04 to 06/05 : 3 Doppler radars: o KP57,35 & KP59,35 (right side; veh./veh. speeds); o KP53,30 (left side; veh./veh. speeds) - 30/04 to 06/05: WAVETRONIX sensor (KP49,1; veh./veh. dataset)
Period 3: 06/05 to 13/05/2014 (week 5) Measure: Automatic speed camera Location: KP55,6 (6,3 km downstream the transition area) 	- 06/05 to 13/05: 3 Doppler radars: o KP57,35 & KP59,35 (right side; veh./veh. speeds); o KP53,30 (left side; veh./veh. speeds) - 08/05 to 09/05: WAVETRONIX sensor (KP49,1; veh./veh. data)

<u>Period 4</u>: 13/05 to 15/06/2014 (weeks 6 to 10) Measure: Base/Reference situation Location: /	- 13/05 to 15/06 : 3 Doppler radars: o KP57,35 & KP59,35 (right side; veh./veh. speeds); o KP53,30 (left side; veh./veh. speeds) - 20/05 to 03/06 & 12/06 to 15/06: WAVETRONIX sensor (KP49,1; veh./veh. data)

3.4.3 Showcase in Belgium - A21/E34 motorway, section Zoersel-Oelegem

3.4.3.1 Location and roadwork characteristics

A21/E34 Motorway - Location and characteristics

The A21/E34 is an important motorway located in the North-East side of Belgium (**Figure 33**). It is an important corridor for European traffic as it connect the Antwerp area (large Belgian city and important maritime port) with the Eindhoven region (NL) and far away the Dusseldorf region (D). In 2010 the annual average daily traffic along the section Zoersel-Oelegem was around 50.000 vehicles (both directions).

Figure 33: Location of the road works along the A21/E34 motorway (red circle)

Figure 34: Details on the location of the road works (red line) and the connecting road network

As shown on **Figure 33**, the road work section was about 10 km long and included a one interchange connecting the N14 with the motorway.

The A21/E34 motorway was built in the early seventies and is composed of 2 lanes (+ a hard shoulder) in each direction (**Figure 35**). A structural rehabilitation of the section Zoersel-Oelegem has been scheduled for 2014.

Figure 35: View of the A21/E34 (between Zoersel & Oelegem) before the 2014 works (structure rehabilitation)

Roadwork main characteristics

The 2014 road works were executed on both side of the A21/E34 between Zoersel and Oelegem; they consisted in a complete structural rehabilitation. The road works were scheduled around two main stages (with some additional intermediate stages):

- Stage 1 (July): replacement of the existing old concrete structure by asphalt base and layers between Oelegem and Zoersel (side towards the Netherlands);
- Stage 2 (Augustus – begin September): replacement of the existing old concrete structure by asphalt base and layers between Zoersel and Oelegem (side towards Antwerpen);

To keep the motorway capacity as high as possible, the temporary traffic management consisted in keeping two lanes open in each direction. As illustrated on the following schemes (**Figure 36** and **Figure 37**), the whole traffic (4 lanes) has been deviated to the side of the motorway that was free of works. The right and left lanes were 2.75m and 2,50m wide respectively.

Remark: it is important to mention that the monitoring equipment operated by BRRC (Wavetronix Smartsensor HD) has been installed on the same location along the whole monitoring campaign; i.e. at KP 23.20 and independently of the considered road work stage and temporary traffic management scheme in place.

This means that the distance between the traffic monitoring device used to record speed data and the start of the lane deviation (KP22.95 during Stage 1; KP23.15 during Stage 2) was different from one period to the other (250m & 50m respectively).

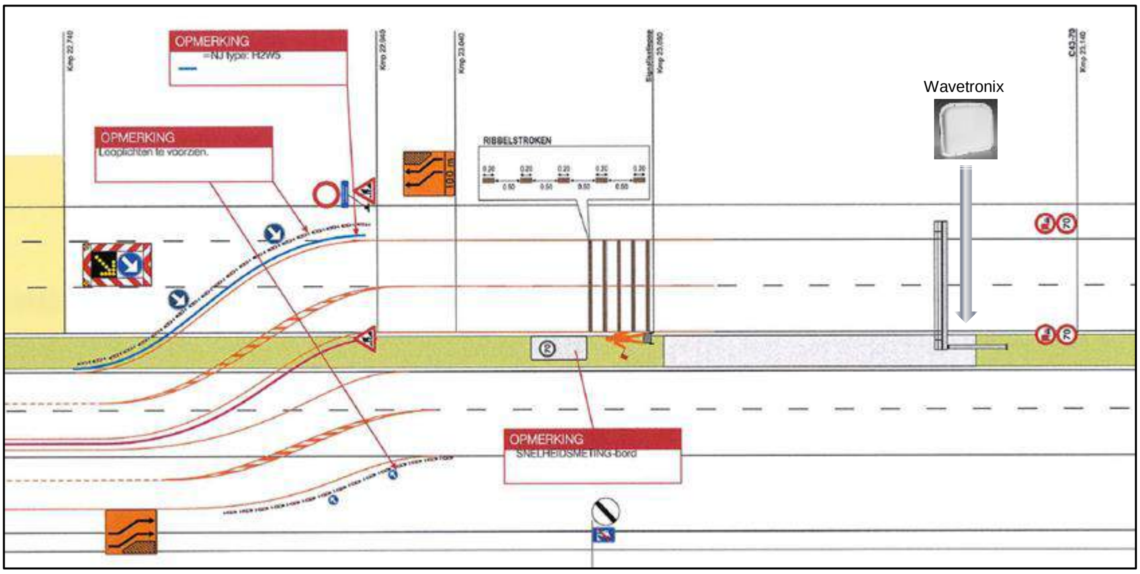


Figure 36: Temporary traffic management during <u>Stage 1</u> (lane deviation start at KP 22.95)

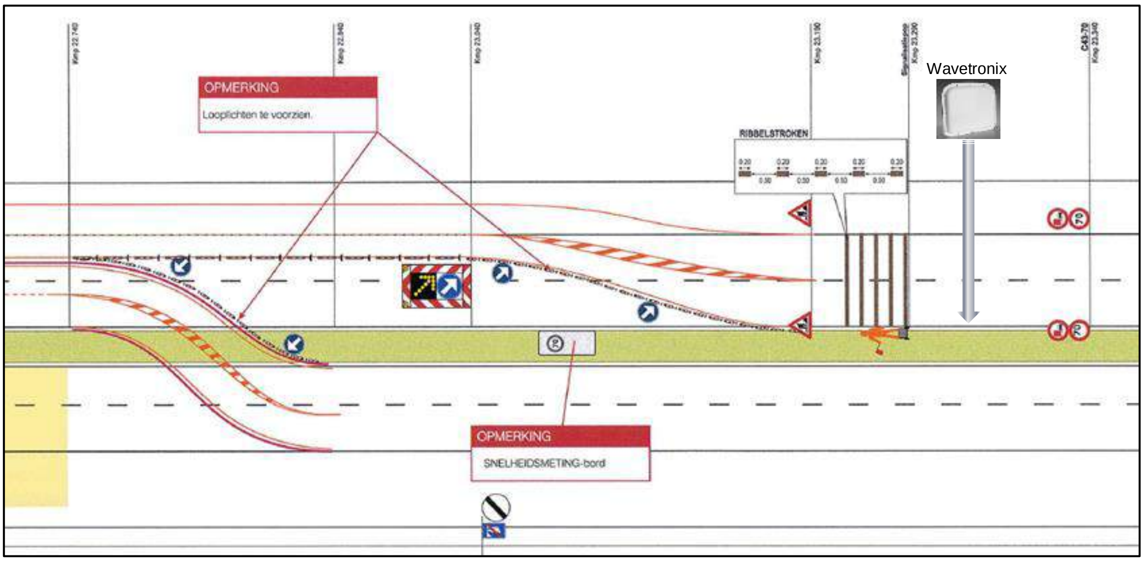


Figure 37: Temporary traffic management during <u>Stage 2</u> (lane deviation start at KP 23.15)

Signing and equipment (base/reference situation)

Figure 38 shows the temporary road signs installed along the advance warning area as well as the speed limit scheme. This signing scheme complies with the federal and regional regulations.

Previous schemes and following tables show that the speed was (only) limited to 70km/h along the lane deviation and in the crossing of the central reserve. Such a practice is not much common on Belgian motorway (in such situations speed is usually limited to 50km/h).

Consequently the design of the transition area has been adapted (longer transition, softer deviation angle) to provide safe traffic condition. In particular the opening of the central reserve has been enlarged to around 150m. This testing site therefore provides a very interesting showcase situation.

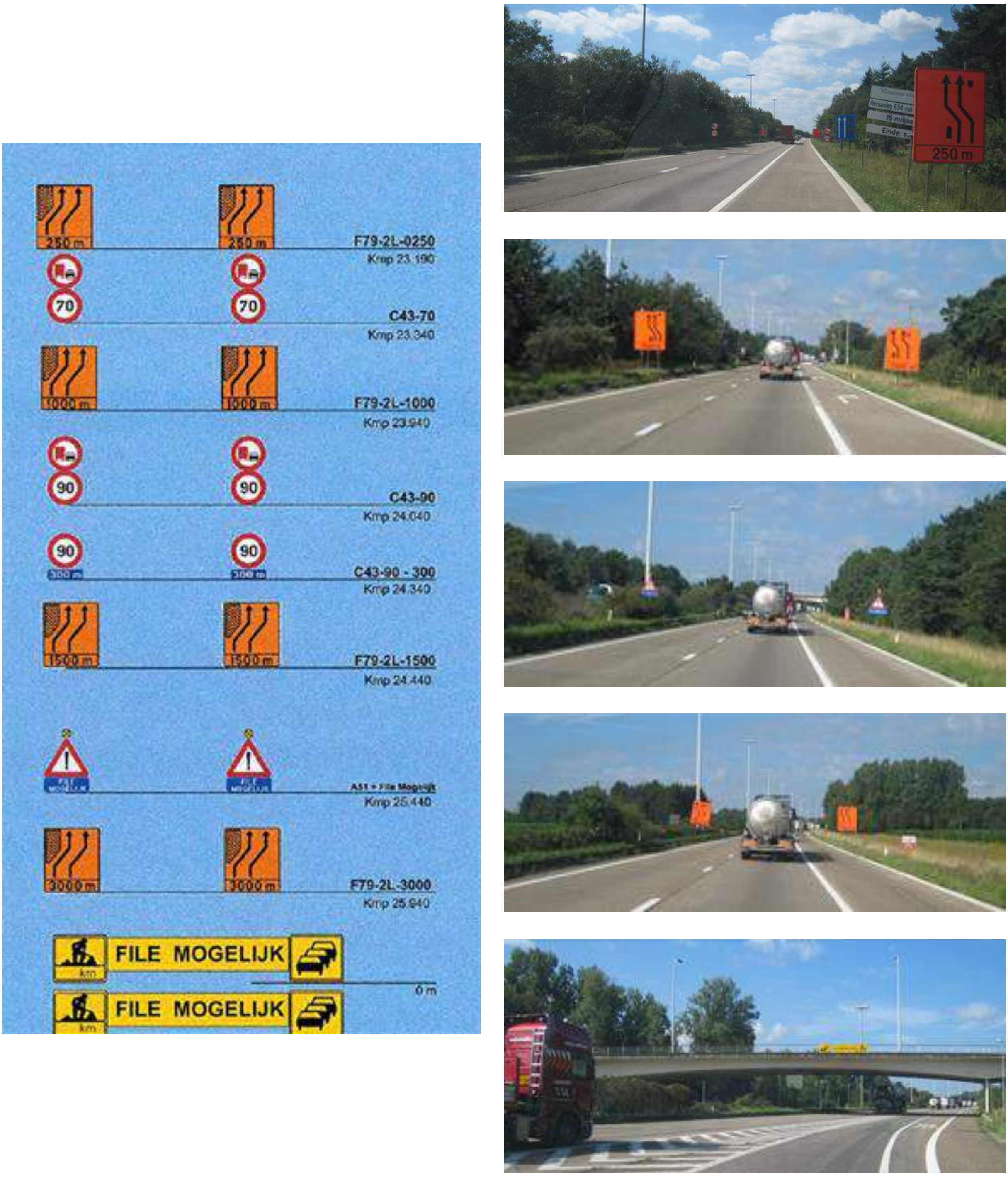


Figure 38: A21/E34 - Road work signing scheme

Additional signs or dedicated devices were used to warn and inform drivers about the road work layout or about the accessible exits along the work zone (**Table 6**, respectively for stage 1 and stage 2).

Table 6: A21/E34 road works – Additional signs and dedicated devices along advanced warning and transition areas

KP (km)	Distance from a reference Point	Road sign, marking & equipment (Stage 1)	Type
27.40	- 4450m		Road user warning – Road work ahead
23.20	- 250m		Remind Speed limit and overtaking restriction (temporary gantry)
23.10	- 150m		Dynamic Speed Display
23.00	- 50m		Transversal Rumble strips
22.95	0 m		Remind Speed limit and Warning about possible Speed enforcement (mobile VMS trailer)

22,90	Crossover		Two adjacent lanes separated by a 1m wide neutral area)

KP (km)	Distance from a reference Point	Road sign, marking & equipment (Stage 2)	Type
27.40	- 4450m		Road user warning – Road work ahead
23.20	- 250m		Remind Speed limit and overtaking restriction + Dynamic Speed Display & Transversal Rumble strips
23.15	0m (Lane deviation)		Two adjacent lanes separated by a 1m wide neutral area)
22.95	+200m		Remind Speed limit and Warning about possible Speed enforcement (mobile VMS trailer)

Road user's information

The Flemish Road Agency organized communication to the road users through the media, and particularly via their website[7]. Information was provided about the work in progress, the different stages and traffic management issues, as shown on **Figure 39**.

[7] http://www.wegenenverkeer.be/wegenwerken

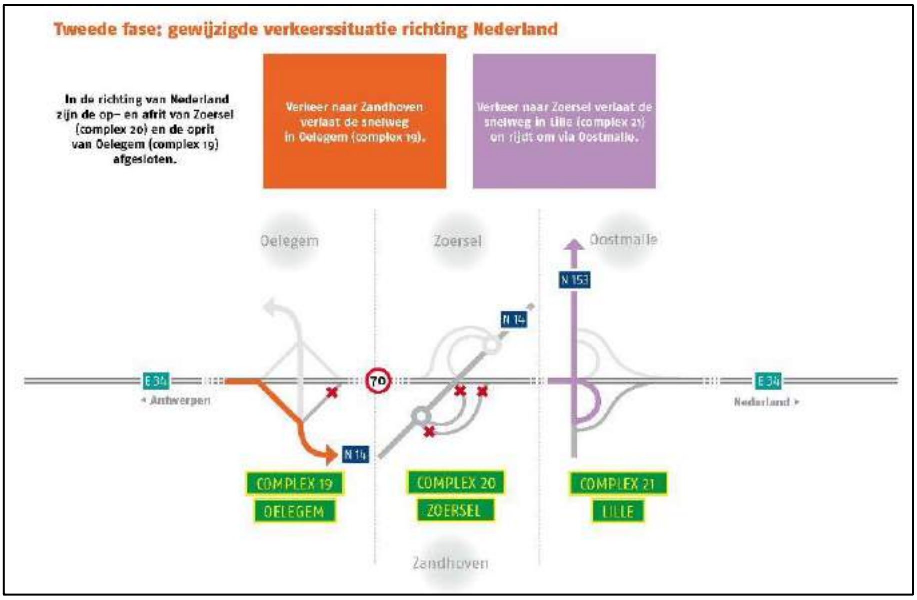


Figure 39: A21/E34 Zoersel – Oelegem road work: example of web communication to the road users

Where available fixed Variable Message Signs were also used to inform and warn drivers about road works, incidents and traffic management measures.

3.4.3.2 Speed management measures and Monitoring equipment

Speed management measures

As presented along the previous chapter various devices were installed along the advanced warning and transition areas (VMS, temporary gantry, speed display, rumble strips) and no additional Speed management measures were deployed during the monitoring campaign[8].

Monitoring equipment

A Multilane Wavetronix Smartsensor HD (digital wave radar) owned and operated by BRRC has been installed close to the transition area. This detector monitored traffic on the two adjacent lanes. As explained before the Wavetronix Sensor has been installed on the same location along the whole monitoring campaign; i.e. at KP 23.20 and independently of the considered road work stage and temporary traffic management scheme in place (**Figure 40**).

This means that the distance between the traffic monitoring device used to record speed data and the start of the lane deviation (KP22.95 during Stage 1; KP23.15 during Stage 2) was different from one period to the other (250m & 50m respectively).

[8] An automatic speed camera was supposed to be deployed during the monitoring period by the Police but has been canceled.

Figure 40: BRRC Wavetronix Smartsensor HD (digital wave radar) at KP 23.20

3.4.3.3 Available data

The Wavetronix sensor has been installed on the 16th of July 2014 and removed on the 15th of September. The first layout (stage 1 mentioned in 3.4.3.1) has been in place along July and until the 1st of August. It has been immediately followed by the second layout (stage 2) that ended on the 05th of September.

The Wavetronix device encountered some technical problems (software, battery) along the monitoring period. As a consequence the following data sets (**Table 7**) were available (after filtering as exposed in the chapter 3.3.6.2).

Table 7: A21/E34 road work: data available from the speed monitoring campaign

Road Work configuration	(5 minutes aggregated) **Data**
<u>Stage 1</u>: Begin of July till 01/08/2014 <u>Measure</u>: Base/Reference situation (cf. chapter 3.4.3.1) 	Wavetronix (KP23,20): - veh./veh. Dataset; - 16/07 till 18/07 & 23/07 till 01/08; - Right & left lanes.
<u>Stage 2</u>: 01/08 till 05/09/2014 <u>Measure</u>: Base/Reference situation (cf. chapter 3.4.3.1) 	Wavetronix (KP23,20) - veh./veh. Dataset; - 01/08 till 06/08; 13/08 till 14/08 & 04/09 till 05/09; - Rright & left lanes.

3.4.4 Showcase in the Driving simulator, Italy

Due to national regulations or road work site constraints some important parameters, such as speed limits, lanes width or geometry of the lane deviation when crossing the central reserve can't be easily tested in a showcase. The University of Florence (UNIFI) therefore proposed to carry out a complementary analysis (not planned in the project proposal) through an experiment in its driving simulator.

In this paragraph the outcomes of a study performed with the driving simulator of the Road Safety and Accident Reconstruction Laboratory (LaSIS) of the University of Florence are shown.

3.4.4.1 Introduction

The study was designed to evaluate the effect of different configurations of a work zone crossover, identified (in the WP3) as a very critical layout for safety, on drivers' behaviour.

The research is divided in the following phases:

- definition and implementation at the driving simulator of a crossover work zone designed in accordance with the Italian Ministerial Decree 10 July 2002 (Ministero delle Infrastrutture e dei Trasporti, 2002). This configuration was called "configuration 0";
- analysis of the speeds in the different work zone areas;
- definition and implementation at the driving simulator of alternative configurations of the work zone ("configuration 1", "configuration 0_VMS", "configuration 2", "configuration 3");
- comparative analysis of the effects induced by the new configurations on the driver's behaviour with particular reference to the actual speeds.

3.4.4.2 Driving simulator

The driving simulator used for the tests is one of the most advanced available in Italy, equipped with a full scale vehicle (Lancia Ypsilon, **Figure 41**) fitted on a 6 degrees of freedom Stewart's platform, allowing roll, yaw and pitch.

Figure 41: The dynamic driving simulator at the University of Florence

The driver, inside the cabin, is immersed in a virtual environment in which all the sensorial stimuli typical of driving are faithfully reproduced. The visual reproduction of the road scenario is obtained by means of four projectors installed on the ceiling, projecting on a cylindrical screen embracing an angle wider than 200 degrees. The three rear mirrors are replaced by 6.5” LCD monitors, reproducing the rear vision. The sound is generated by a multichannel audio system, capable to reproduce both the vehicle and the environmental noise. All the functions are supervised by a network of 5 computers, including an operator’s station from which the simulation is managed.

3.4.4.3 Participants

The participants were recruited on a voluntary basis among the students and staff of the University of Florence according to the following criteria: possession of a valid Italian driver’s license, with at least five years of driving experience and an annual driving distance greater than 5000 km.

Twenty six subjects participated in the research, 7 women and 19 men. Age varied between 24 years and 50 years (mean value: 37.3 years; standard deviation: 8.3 years). Their driving experience (measured in terms of years of driving license possession) varied between 5 years and 31 years (mean value: 17.9 years; standard deviation: 7.8 years).

3.4.4.4 Scenarios’ design

The analysed scenario is based on a 2+2 four lane motorway with a standard speed limit of 130 km/h. The cross section of the carriageway was equal to that of the main Italian highways and it was composed by two lanes, each 3.75 m wide, and a 2.50 m large shoulder with a roadside barrier and a median barrier. The median barrier was 3 m wide.

Five different configurations of the crossover work zone were designed on the same section of motorway about 7 km long and implemented in the driving simulator.

For the creation in virtual reality of the motorway scenario with the different work zone configurations, particular attention has been placed on temporary signs and barriers, all built using a three dimensional software and introduced in the simulator scenario.

The experimentations on the different work zone configurations were carried out during daylight conditions and using dry pavement conditions.

Configuration 0

The type of work zone is a crossover in which the traffic flow is diverted to the opposite carriageway where two traffic flows travel in opposite directions, each on one lane (**Figure 42**).

The speed is progressively reduced from 130 to 60 km/h and in the by-pass to 40 km/h. The signs are consistent with the instructions of the Italian technical rules for temporary signs (Ministero delle Infrastrutture e dei Trasporti, 2002).

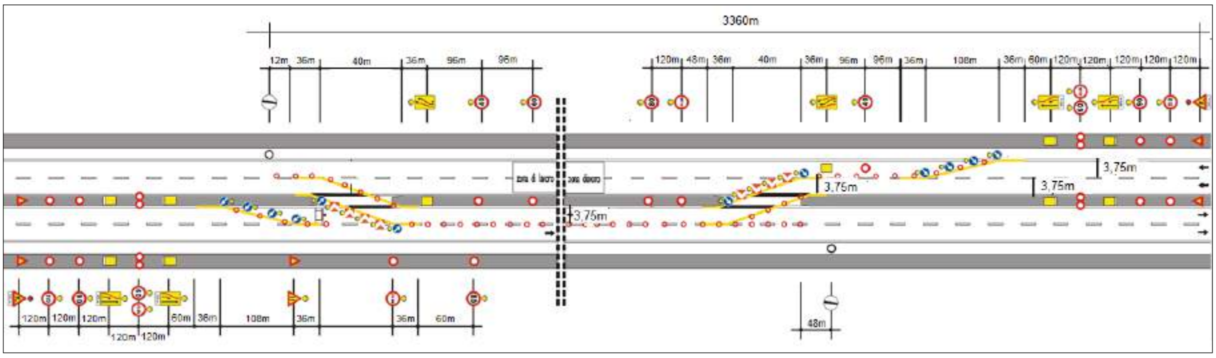


Figure 42: The configuration "0"

The alignment implemented on the simulator is composed by the following sections:

- an initial 3500 m long section, without interference with the work zone;
- a section of 3360 m that includes advancing warning area, activity area and termination area.

The advance warning area is 700 m long and contains five pairs of signs with one sign located on each side of the roadway. The first pair of signs consists of the "road work" signs. The other traffic signs are located at a distance of 120 m from each other and consist of:

- 110 km/h speed limit signs;
- 90 km/h speed limit signs;
- signs that indicates the closure of the right lane;
- 60 km/h speed limit signs;
- Repetition of the "right lane closure" signs.

Approximately 90 m after the "right lane closure" signs there is the transition area, which consists of a taper (realized with delineators and "keep left" signs) that close the right lane over a length of about 108 m followed by a section with a single lane approximately 250 m long (**Figure 43**).

Figure 43: The transition area as seen by the driving simulator participants

In this section the speed limit is reduced to 40 km/h. The speed limit sign is placed about 100 m before the end of the transition area, followed by the "carriageway closure" sign placed 36 m before the "entrance by-pass" (**Figure 44**), that shifts the traffic flow in the activity area across the median. The median opening is 40 m wide.

Figure 44: The “carriageway closure” sign in approach to the “entrance by-pass”

The area corresponding to the work zone activity area is approximately 2 km long. In this section the two opposite traffic flows are concentrated on a single roadway, with a single lane for each travel direction.

The channelizing devices used to separate the traffic flows consist of flexible delineators placed at a distance of 12 m from each other.

Moving along this section the user encounters a “No Overtaking” sign placed about 85 m after the by-pass, then, at a distance of 120 m, the “80 km/h speed limit” sign. The speed limit is subsequently reduced prior to 60 km/h and then to 40 km/h. The “40 km/h speed limit” sign is placed about 100 m before the exit by-pass that moves the traffic back across the median (**Figure 45**).

The termination area includes the taper to direct the traffic back into travel roadway after traversing the activity area. This area ends with the ”End of road work” sign, placed 48 m after the exit by-pass.

Figure 45: The “exit by-pass” experienced by the participants

Configuration 0_VMS

This configuration is different from the "Configuration 0" due to the installation of a Variable Message Sign in place of the "road work" sign on the right shoulder (**Figure 46**).

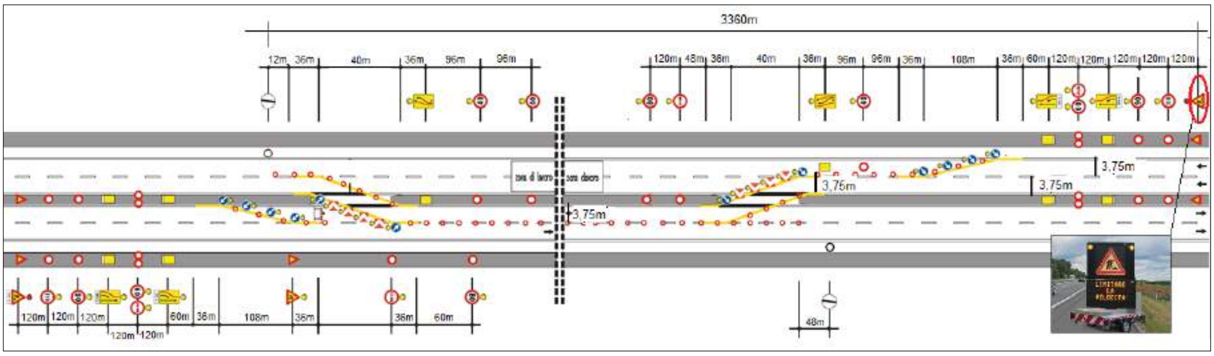


Figure 46: The configuration "0_VMS"

The message implemented in the VMS sign reads "Riduci la velocità" ("Reduce the speed" in Italian, **Figure 47**).

Figure 47: Picture of the VMS sign displayed in the simulator

This choice was based on the findings of the WP2. In fact the study of Garber & Patel (2001), that examined the effects of four different messages in Virginia work zones, evaluated the message "You are speeding, slow down" as the most successful on reducing the mean and the 85th percentile of speeds. This message successfully singled out drivers, as they perceived the meaning that this message was not a general warning.

Configuration 1

The configuration "1" is different from the configuration "0" due to the wider median opening (80 m instead of 40 m). Furthermore the sequence of speed limits in the advance warning area is 110-80 km/h, instead of the sequence 110-90-60 km/h used in the "configuration 0". Furthermore the limit of 40 km/h in the by-pass was increased to 60 km/h (**Figure 48**). Also the speed limits within the activity area are different: the limit of 60 km/h and 40 km/h are increased respectively to 80 km/h and 60 km/h.

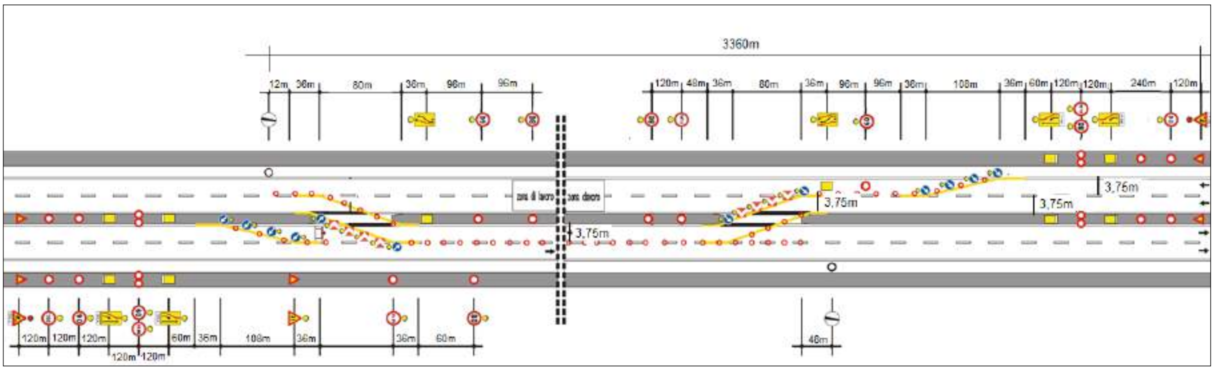


Figure 48: The configuration “1”

Configuration *2*

The layout of traffic signs of this configuration is the same of that implemented in the configuration “0”. Also the median opening is the same (40 m). However in the “Configuration 2” the lane width for the flow travelling through the work zone is increased from 3.75 m to 5 m. The 5 meter lane is achieved through the lateral displacement of delineators and of the yellow lines (with the original white lines left in place) (**Figure 49**).

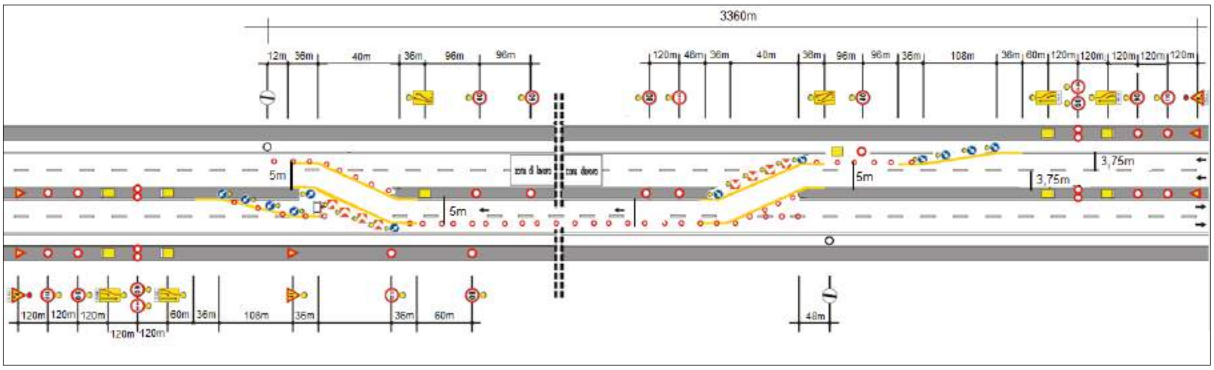


Figure 49: The configuration “2”

Configuration 3

This configuration (**Figure 50**) is formed by using the same sequence of signs and the same opening width implemented in configuration 1 and by using a lane width of 5 m for the flow travelling through the work zone (such as configuration 2).

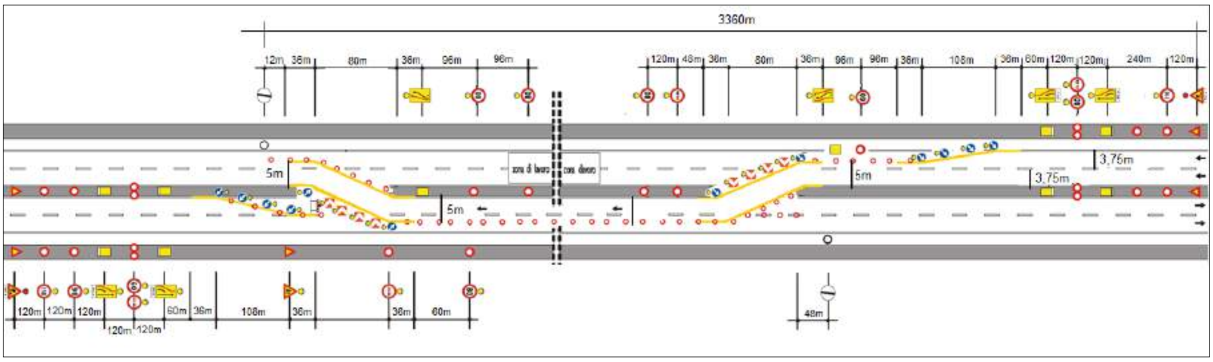


Figure 50: The configuration “3”

3.4.4.5 Testing Procedure

Upon their arrival in the laboratory, each participant was briefed on the requirements of the experiment and read and signed an informed consent document.

Before seating on the car, each subject was given some basic information on the use of the simulator and the behaviour to maintain during the test; in particular they were asked to wear safety belt and drive normally, respecting the rules of the Road Code and driving in the most natural possible way. The subjects were warned about simulator sickness and told they could stop the test in any moment.

The participants were not briefed about the objectives of the research.

The drivers were then taken to the driving simulator to perform a 10 minutes training phase to familiarize them with the vehicle and its control instruments (steering wheel, gearbox, accelerator, brakes, on/off switching of headlights). The training scenario was a motorway section, with moderate traffic.

At the end of the training phase, the subject was asked to get down from the cabin and fill a post-training questionnaire. After a 5 minutes rest in order to re-establish psycho-physical conditions similar to those at the beginning of the test, the drivers started the experimental session with the first of five testing configurations.

In order to reduce bias within the data collection, each participant randomly and equally encountered each of the 5 configurations in varying random order.

3.4.4.6 Data collection

The scenario was programmed also to acquire and save the following values, with the sampling time set to 0.05s:

- relative time (s);
- position coordinates X and Y (m);
- speed (m/s);
- accelerations along X and Y axes (m/s^2).
- offset from the centre of the lane (m);
- reaction on pedals (accelerator, brake and clutch);
- wheel position (radians);
- gear engaged.

Although the simulator collected a great number of parameters, in this first part of study only speeds were analyzed based on the result of the literature review that identified speed variations as critical for road safety in work zones.

The local speed was measured every meter. The comparison between the speeds was carried out in the following sections:

- in correspondence of each speed limit sign (site A, B, C, D, E, F, G, H);
- in correspondence of a upstream section located 500 m before the “work zone” sign (site I);
- in correspondence of the “carriageway closure” sign (site J).
- in correspondence of the beginning section of “entrance by-pass” (site K) and of the “exit by-pass” (site L).

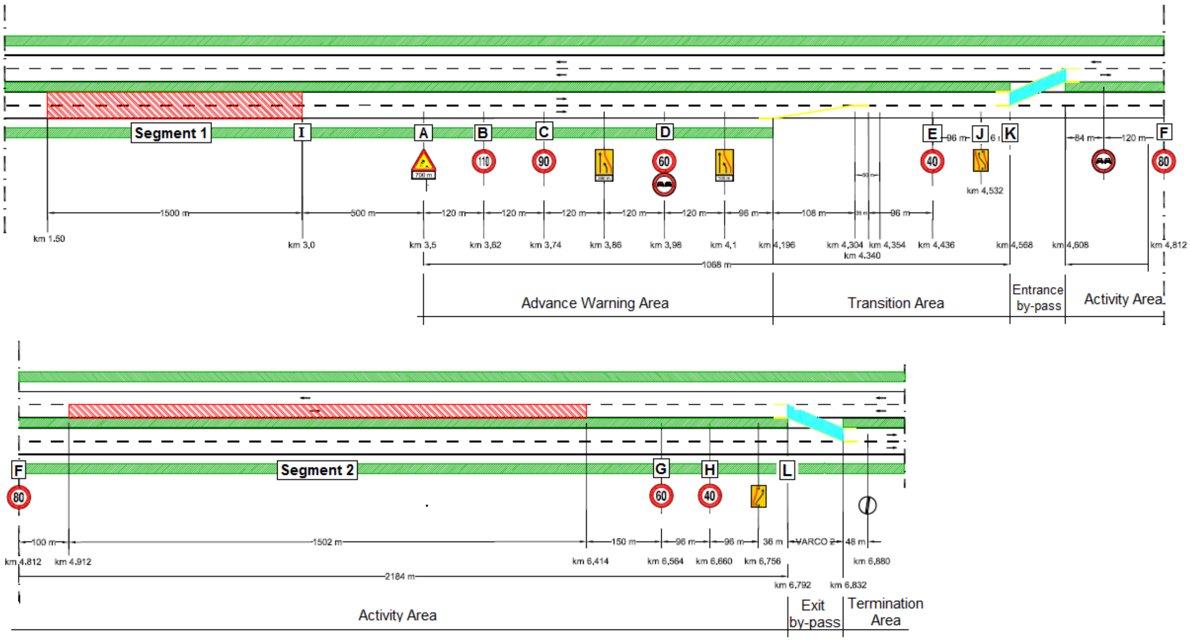


Figure 51: Speed measurement sites

Furthermore also the speeds within a 1.5 km long segment upstream of the work zone (segment 1), along the activity area (segment 2) and within the entrance (segment 3) and the exit by-pass (segment 4) were compared in the different configurations. The speed measurements sites are shown in **Figure 51**.

The analysis of speed data was used as an indicator the driver's perceived risk of travelling through a specific area of the work zone. For the comparative analysis between the configurations, the mean speeds, standard deviations and speed variances were calculated.

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3.5 Results from the showcase

3.5.1 Czech Republic - D1 motorway, section Prague-Brno

In this chapter results from the Czech showcase are presented. The results are all based on data aggregated on 5 min interval and processed following the filtering method described in chapter 3.3.6.

The scheme in **Figure 52** reminds the location of the detectors as well as the numbering of lanes for each detector and the speed management measures tested during the showcase in the Czech Republic. Speed and traffic were monitored at four locations, Detector no1 - 4 in the picture below, and five different speed management measures (actors) were tested: Advanced LED trailer and Speed Camera Sign in advance of the work zone, Police car, Speed display and VMS trailer in the work zone (more details in chapter 3.4.1).

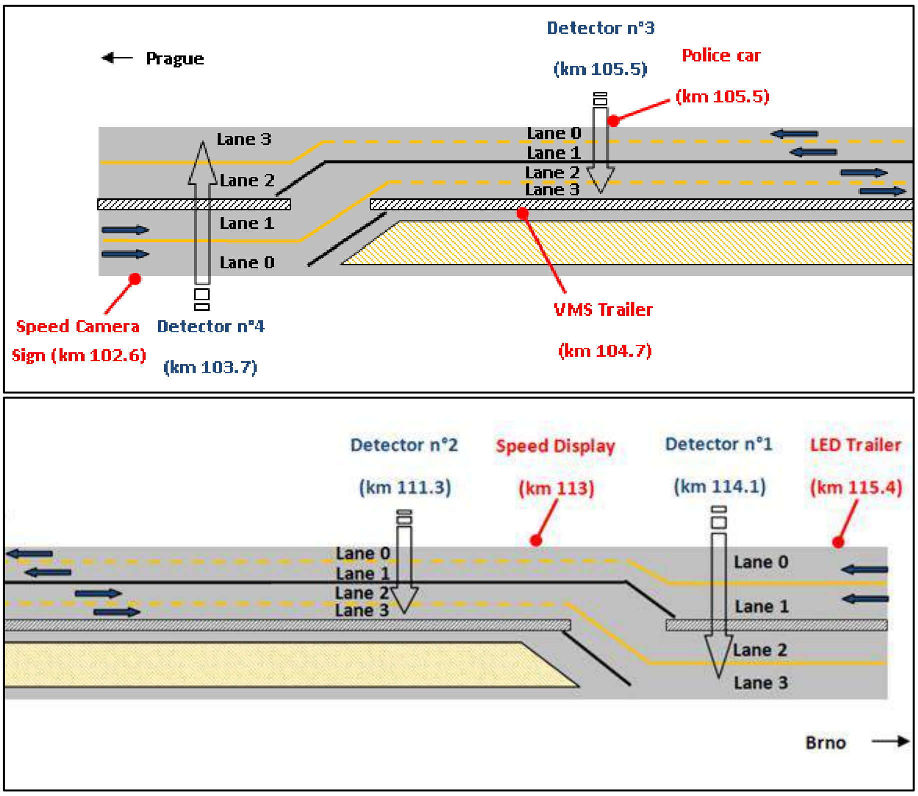

Figure 52: Schematic description of detectors and speed management measures from showcase in the Czech Republic

Table 8 resumes the activation periods of the various measures that have been implemented on site, as well as identifies the detectors that are primarily impacted by the deployment of each measure and for which the data analysis has been performed.

The results presented along the next chapters focus on the detectors located at the black dots in the orange cells in **Table 8**. These are locations were we can expect that the tested actors have a main influence.

Table 8: Activation periods of measures implemented and detectors primarily impacted

					Detector n°1	Detector n°2	Detector n°3	Detector n°4
					dir 1 Prague / dir 2 Brno	dir 1 Prague / dir 2 Brno	dir 1 Prague / dir 2 Brno	dir 1 Brno / dir 2 Prague
					Lane 0 Lane 1 / Lane 2 Lane 3	Lane 0 Lane 1 / no data	Lane 0 Lane 1 / Lane 2 Lane 3	Lane 0 Lane 1 / Lane 2 Lane 3
ACTORS			from	to	speed limit 100 km/h	speed limit 80 km/h	speed limit 80 km/h	speed limit 100 km/h
VMS trailer	signaling scheme A	1 A	5.6. 2014 14:00	20.6. 2014 7:00			●	○
	signaling scheme B	1 B	20.6. 2014 7:00	30.6. 2014 12:00				
LED trailer	signaling scheme A	2 A	13.6. 2014 7:00	20.6. 2014 7:00	●	○		
	signaling scheme B	2 B	20.6. 2014 7:00	30.6. 2014 10:00				
speed display		3	10.7. 2014 12:00	26.7. 2014 12:00		●	○	
speed camera sign		4	19.7. 2014 16:00	26.7. 2014 12:00			○	●
police car (every day between 9:30 and 10:30)		5	5.6. 2014 (e.d)	26.7. 2014 (e.d)			●	○

● main influence
○ secondary influence

analysed situation
omitted situation

Unfortunately it has not been possible to retrieve interesting data from the detector n°2 due to troubles during the data processing (linked to communication problems that occurred during the data collection). Therefore the results hereafter concentrate on data available from detectors 1, 3 and 4.

3.5.1.1 Detector (station) 1: LED trailer Scheme A and Scheme B

Detector 1 was placed at kilometer 114.1 with a distance of about 300 m to the beginning of the transition area. The advanced warning trailer LED was placed at kilometer 115.4, meaning 1300 m before the detector in the direction to Prague. The monitored traffic lanes were:

- Lane 0 - Right traffic lane Prague bound
- Lane 1 - Left traffic lane Prague bound
- Lane 2 - Left traffic lane Brno bound
- Lane 3 - Right traffic lane Brno bound

The LED-trailer shows two different schemes (shown below in **Figure 53**):

1. Road work sign on the upper display and temporary lane configuration on the bottom display (Scheme A);
2. Speed sign “100” on the upper display and HGV restriction for left lane on the bottom display variable message signs to show the road safety requirements (Scheme B).

Figure 53: Advanced warning trailer scheme A and B

The results are presented in **Table 9** and **Table 10**. The speed limit is 100 km/h and the direction where the LED trailer is expected to have an influence on vehicle speeds is the direction to Prague, lane 0 (right lane) and lane 1 (left lane). When scheme A or scheme B is active, only minor changes of mean speed or standard deviations can be seen in the direction to Prague.

Table 9: Mean speeds and standard deviations LED trailer scheme A (detector 1)

Direction	**Lane**	**LED trailer scheme A**	**N**	**Mean**	**Mean difference**	**Std. Deviation**	**Std difference**
Prague	Right	off	7 847	108,2		8,1	
		Active	656	108,1	-0,2	6,9	-1,2
	Left	off	11 471	127,0		8,9	
		Active	1 014	127,5	0,5	8,4	-0,5

Table 10: Mean speeds and standard deviations LED trailer scheme B (detector 1)

Direction	**Lane**	**LED trailer scheme B**	**N**	**Mean**	**Mean difference**	**Std. Deviation**	**Std difference**
Prague	Right	off	7 131	108,2		8,1	
		Active	1 372	108,2	0,0	7,6	-0,5
	Left	off	10 359	127,2		8,8	
		Active	2 126	125,9	-1,3	9,1	0,3

Since data analysis at the Belgian showcases discovered that the period of the day was an important factor when looking at speed behavior, the results are presented both in total and divided in 4 time periods (00-06, 06-12, 12-18 and 18-24) in **Table 11** and **Table 12**.

Table 11: Mean speeds and standard deviations LED trailer scheme A, divided by time of the day (00-06, 06-12, 12-18 and 18-24), station 1.

Direction	**Lane**	**Day Period**	**LED trailer scheme A**	**N**	**Mean**	**Mean difference**	**Std. Deviation**	**Std difference**
Prague	Right	00 - 06	off	3 027	104,0		6,6	
			Active	267	104,1	0,2	6,6	0,0
		06 - 12	off	1 342	112,8		6,7	
			Active	114	112,6	-0,2	4,5	-2,2
		12 - 18	off	973	112,8		7,6	
			Active	61	111,7	-1,1	5,4	-2,2
		18 - 24	off	2 505	109,2		8,0	
			Active	214	109,5	0,3	5,9	-2,1
	Left	00 - 06	off	2 789	123,8		12,1	
			Active	239	124,5	0,7	13,5	1,4
		06 - 12	off	2 886	127,9		6,1	
			Active	264	128,6	0,6	4,9	-1,2
		12 - 18	off	2 855	127,1		7,0	
			Active	259	126,1	-1,0	4,6	-2,4
		18 - 24	off	2 941	128,8		8,7	
			Active	252	130,7	1,9	6,5	-2,2

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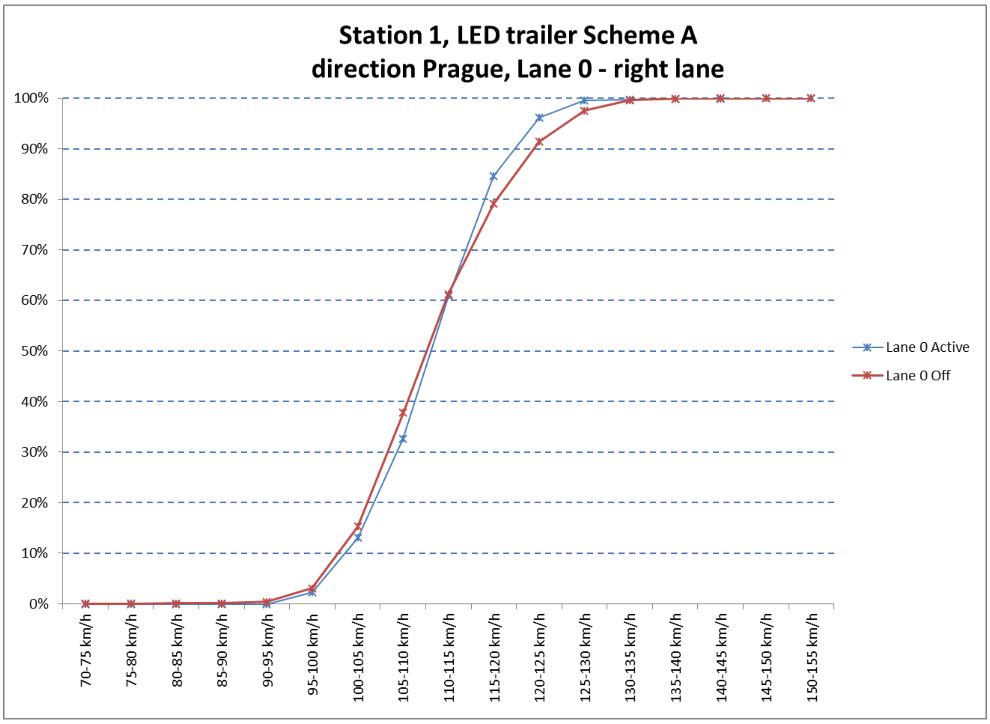
Table 12: Mean speeds and standard deviations LED trailer scheme B, divided by time of the day (00-06, 06-12, 12-18 and 18-24), station 1

Direction	Lane	DayPeriod	LED trailer scheme B	N	Mean	Mean difference	Std. Deviation	Std difference
Prague	Right	00 - 06	off	2 762	104,0		6,5	
			Active	532	104,0	0,1	7,5	1,1
		06 - 12	off	1 229	113,2		6,7	
			Active	227	110,6	-2,5	5,1	-1,6
		12 - 18	off	912	112,6		7,8	
			Active	122	114,0	1,5	4,8	-3,0
		18 - 24	off	2 228	109,0		8,0	
			Active	491	110,2	1,2	7,0	-1,0
	Left	00 - 06	off	2 526	124,2		12,0	
			Active	502	122,2	-2,0	13,3	1,3
		06 - 12	off	2 636	128,4		5,9	
			Active	514	126,0	-2,4	6,3	0,4
		12 - 18	off	2 595	127,3		6,9	
			Active	519	125,6	-1,7	6,2	-0,7
		18 - 24	off	2 602	128,9		8,7	
			Active	591	129,2	0,3	7,6	-1,1

In **Figure 54**, the speed distributions are shown for LED-trailer scheme A direction to Prague, lane 0 (right lane) and lane 1 (left lane). The graph indicates no major changes of the speed distributions. The speed compliance is very low in both lanes, but as expected worse in the left lane. Similar graphs for scheme B are shown in Appendix 2.



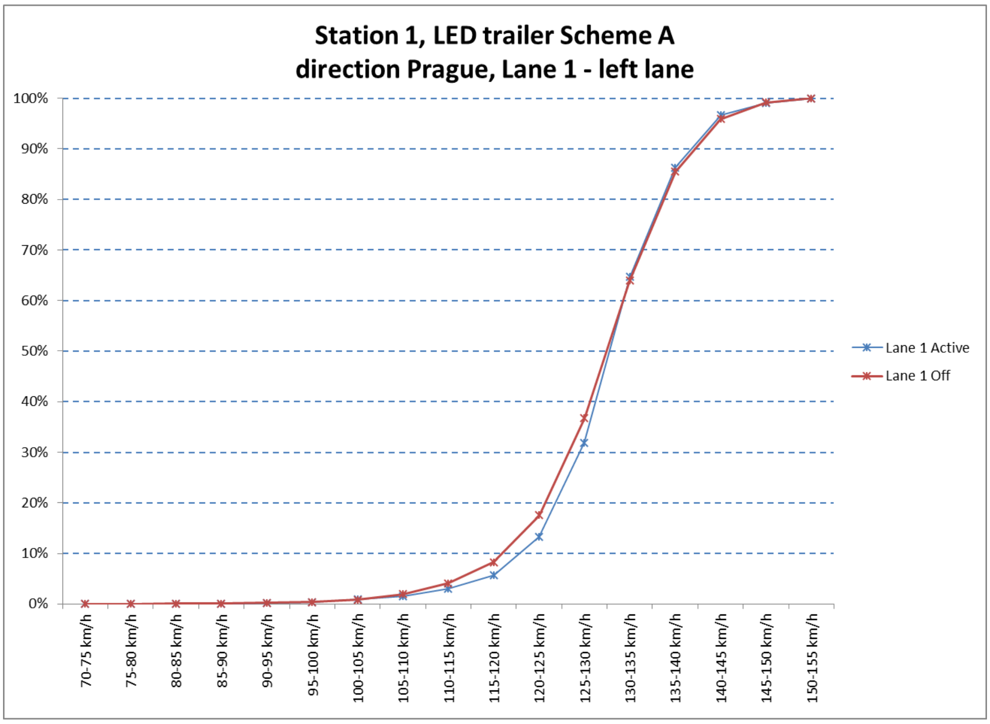


Figure 54: Speed distributions, right and left lane, LED trailer scheme A, direction to Prague

3.5.1.2 Detector (station) 3: VMS trailer

Detector 3 was placed at kilometer 105.5 with a distance of 1.3 km to bottleneck. The VMS trailer was located at kilometer 104.7 (800 meters before the detector) and was used to inform the drivers of speeding. Two warning displays were tested: current speed + message "Reduce you speed" (ZPOMAL) or speed limit sign + "Reduce you speed" (ZPOMAL).

Figure 55: Schematic description of VMS trailer and the displays.

The monitored traffic lanes were:

- Lane 0 - Right traffic lane Prague bound
- Lane 1 - Left traffic lane Prague bound
- Lane 2 - Left traffic lane Brno bound
- Lane 3 - Right traffic lane Brno bound.

The results are presented in **Table 13** and **Table 14** below. The speed limit is 80 km/h and the direction where the VMS-trailer is expected to have an influence on vehicle speeds is the direction to Brno. When the VMS is active, the tendency for Scheme A is that a small decrease can be observed for both mean speeds and standard deviations in the direction to Brno. For VMS scheme B, there are similar tendencies for the standard deviations, but it must be noticed that there are very few observations when the VMS scheme B is active and the comparisons are therefore not really appropriate.

Table 13: Mean speeds and standard deviations VMS trailer scheme A (detector 3)

Direction	Lane	VMS Trailer scheme A	N	Mean	Mean difference	Std. Deviation	Std difference
Brno	Right	off	1 571	92,8		5,0	
		Active	1 125	90,4	-2,5	4,3	-0,6
	Left	off	3 252	99,0		10,7	
		Active	2 466	98,2	-0,8	10,1	-0,6

Table 14: Mean speeds and standard deviations VMS trailer scheme B (detector 3)

Direction	Lane	VMS Trailer scheme B	N	Mean	Mean difference	Std. Deviation	Std difference
Brno	Right	off	2 685	91,81		4,86	
		Active	11	92,88	1,1	2,83	-2,0
	Left	off	5 571	98,68		10,52	
		Active	147	98,59	-0,1	7,09	-3,4

The results for VMS scheme A divided in 4 time periods (00-06, 06-12, 12-18 and 18-24) are shown in **Table 15**. Scheme B is not presented divided into time periods due to the limited number of data when VMS scheme B is active. No major differences across the time periods can be observed.

Table 15: Mean speeds and standard deviations VMS trailer scheme A, divided by time of the day (00-06, 06-12, 12-18 and 18-24, detector 3)

Direction	Lane	DayPeriod	VMS Trailer scheme A	N	Mean	Mean difference	Std. Deviation	Std difference
Brno	Right	00 - 06	off	882	91,7		5,2	
			Active	627	89,3	-2,4	4,2	-1,0
		06 - 12	off	125	94,7		4,3	
			Active	107	91,1	-3,7	4,2	-0,1
		12 - 18	off	34	93,7		3,8	
			Active	27	89,2	-4,5	5,2	1,4
		18 - 24	off	530	94,3		4,1	
			Active	364	92,0	-2,3	3,9	-0,2
	Left	00 - 06	off	872	96,9		14,9	
			Active	627	97,5	0,7	14,4	-0,5
		06 - 12	off	777	99,5		7,6	
			Active	566	97,4	-2,0	8,7	1,2
		12 - 18	off	763	98,4		7,0	
			Active	608	97,2	-1,3	6,0	-1,0
		18 - 24	off	840	101,5		10,2	
			Active	665	100,4	-1,1	8,9	-1,3

In **Figure 56**, the speed distributions are shown for VMS trailer scheme A, direction to Brno, lane 3 (right lane) and lane 2 (left lane). The figures show that the speed distribution in the right lane is slightly shifted to the left when VMS-trailer is active, indicating a slightly better speed compliance with speed limit. For both lanes, the speed compliance is low.

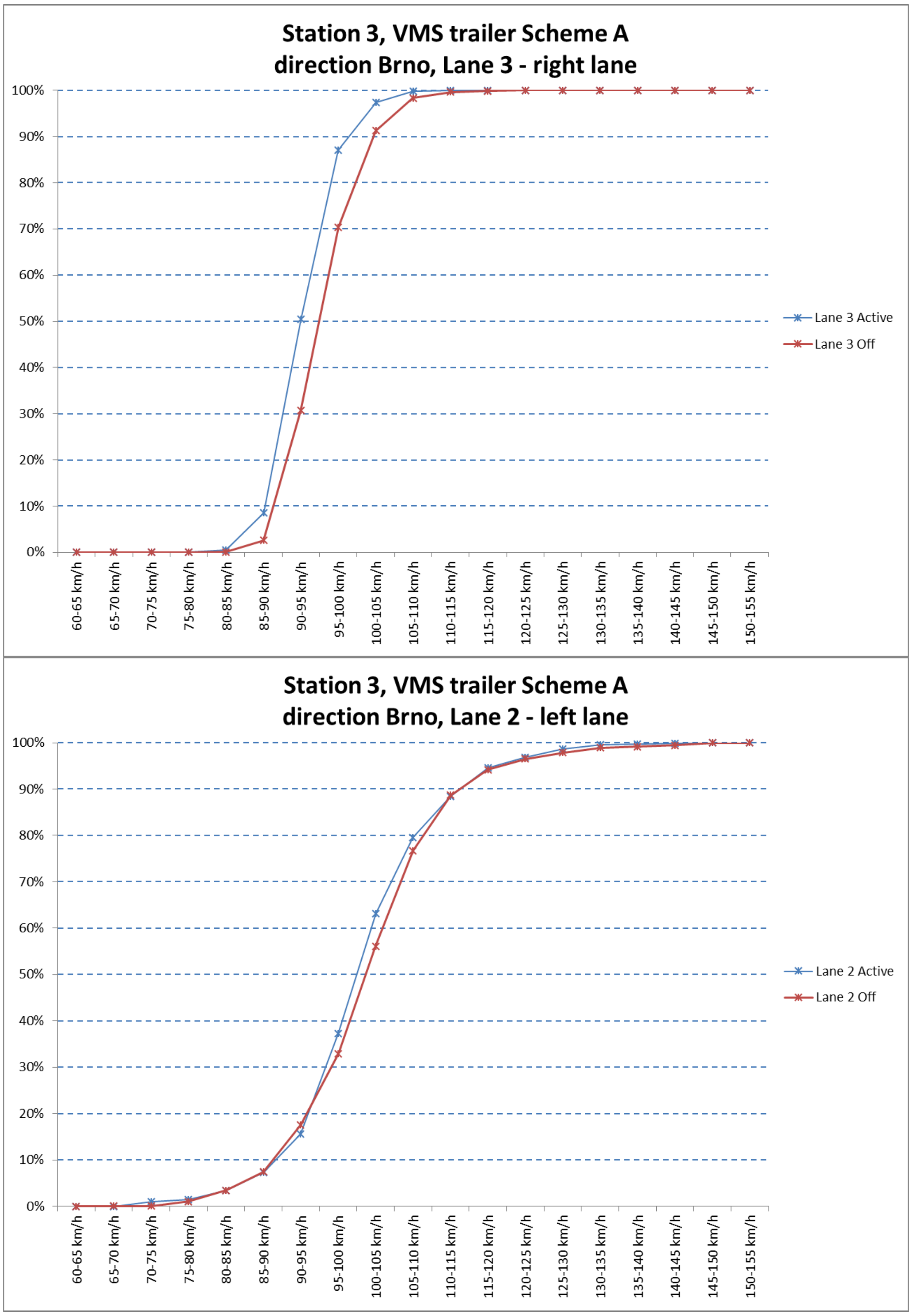


Figure 56: Speed distributions, right and left lane, VMS trailer, direction to Brno

3.5.1.3 Detector (station) 3: Police car

Detector 3 was placed at kilometer 105.5 and the police car was located approximately at the same location. The speed limit is 80 km/h. Within the showcase it was agreed that a police patrol regularly would be present between 9.30 and 10.30 every day. The police car was placed in the direction to Prague, around 100 meters after detector 3 and visible in both directions (see chapter 3.4.1.2 for a description). The most influence of the Police car at detector 3 should therefore be in the direction to Brno (detector being located around 100m after the Police car in this direction).

The results are presented in **Table 16**. The results are shown for the time period 06-12 when the police car is present 09:30-10:30. This means that the active period is between 9:30 and 10:30 and the off-period is between 06:00 – 9:30 and 10:30 – 12:00. Looking at the mean speeds and standard deviations in **Table 16** when the police car is present, small decreases of mean speeds as well as standard deviations can be observed in the direction to Brno, while there is no positive effect measured in the direction to Prague.

Table 16: Mean speeds and standard deviations police car present time period 06-12. Active means police car present 9:30 – 10:30 and off means no police car present (06:00 – 9:30 and 10:30 – 12:00)

Direction	Lane	DayPeriod	Police Car	N	Mean	Mean difference	Std. Deviation	Std difference
Prague	Right	06 - 12	off	237	85,0		4,8	
			Active	53	85,1	0,1	3,9	-0,9
	Left	06 - 12	off	942	93,6		7,7	
			Active	459	94,4	0,8	7,6	-0,1
Brno	Left	06 - 12	off	911	98,8		8,2	
			Active	432	98,2	-0,6	8,1	-0,1
	Right	06 - 12	off	189	93,4		4,7	
			Active	43	91,5	-1,9	4,2	-0,4

In **Figure 57** below, the speed distributions are shown for police car present in direction to Brno for the time period 06-12 (the time period when the police car is present 9.30 – 10.30). Similar graphs for the direction to Prague are shown in Appendix 2. The figures show a shift of the speed distribution to the left in the direction to Brno for the right lane and a tendency of a larger shift for the higher speeds. In the left lane the shift of the speed distribution is very limited.

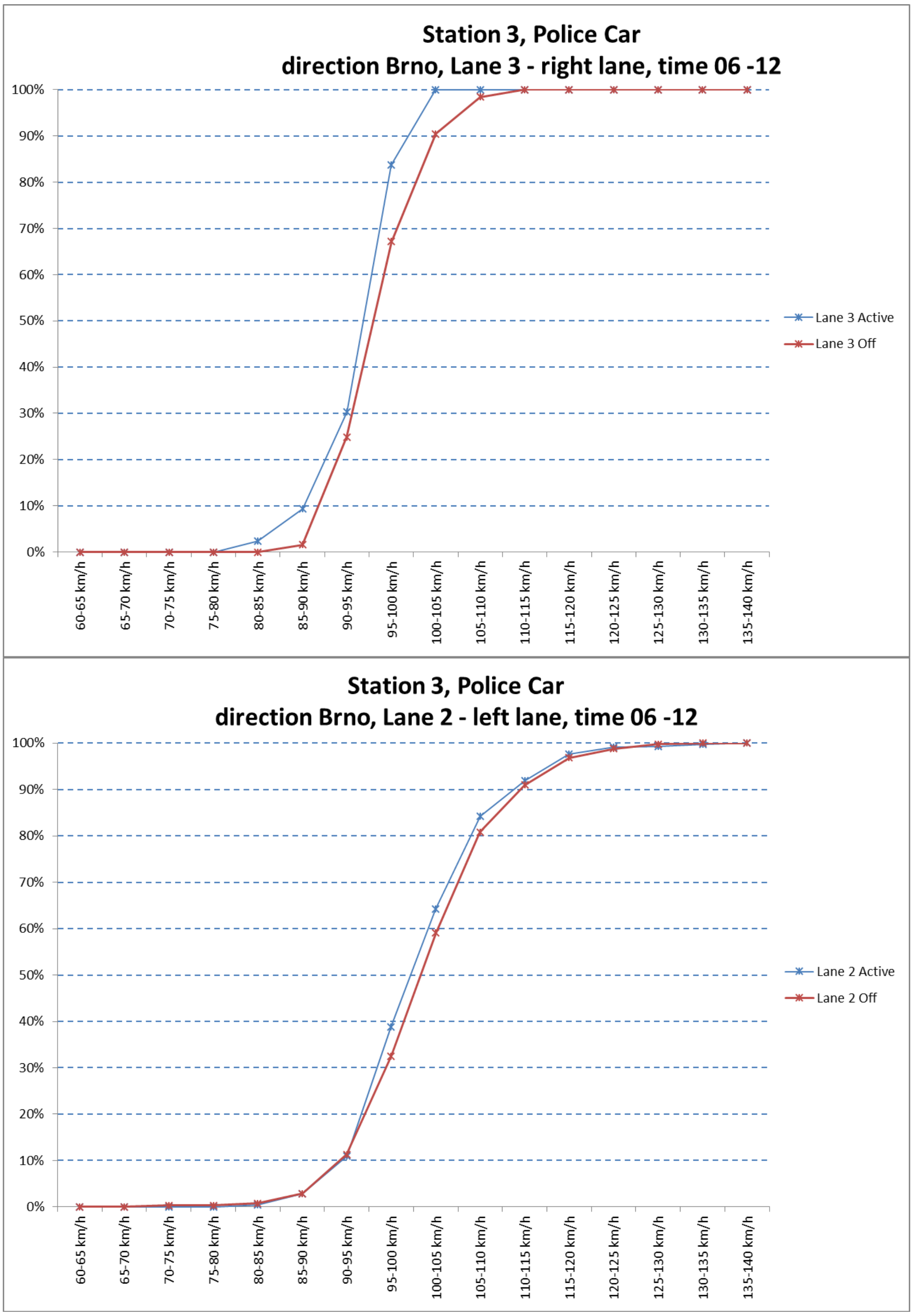


Figure 57: Speed distributions, right and left lane, police car present, direction to Brno

3.5.1.4 Detector (Station) 4: Speed camera sign

Detector 4 was located at kilometer 103.7 and the speed camera sign was located at 102.6 (1100 meters before the detector) informing the drivers that a speed camera is likely to be present (**Figure 58**).

Figure 58: Speed camera sign

The monitored traffic lanes were:

- Lane 0 - Right traffic lane Brno bound
- Lane 1 - Left traffic lane Brno bound
- Lane 2 - Left traffic lane Prague bound
- Lane 3 - Right traffic lane Prague bound.

The results are presented in **Table 17**. The speed limit is 100 km/h and the direction where the speed camera sign is expected to have an influence on vehicle speeds is the direction to Brno. The results show that mean speeds as well as speed standard deviations are lower in the direction to Brno when the speed camera sign is present on site.

Table 17: Mean speeds and standard deviations speed camera sign (detector 4)

Direction	Lane	Speed Camera Sign	N	Mean	Mean difference	Std. Deviation	Std difference
Brno	Right	off	10 272	108,0		7,8	
		Active	640	105,5	-2,5	6,3	-1,5
	Left	off	13 255	123,0		9,2	
		Active	1 033	118,8	-4,2	7,8	-1,4

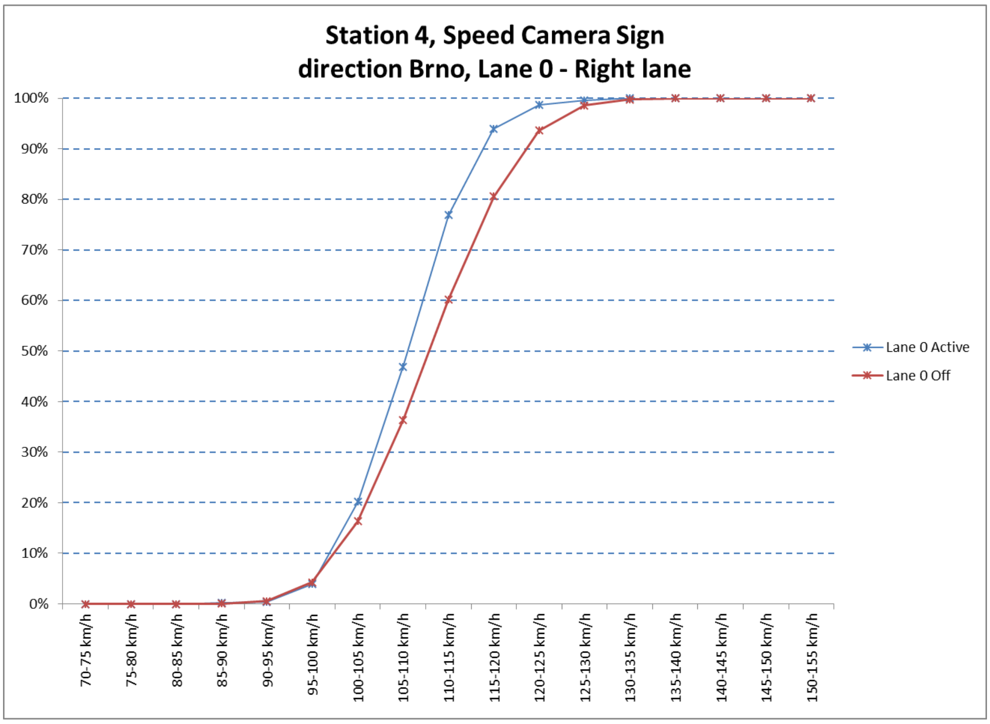
The results divided by time of the day (00-06, 06-12, 12-18 and 18-24) are shown in **Table 18**.

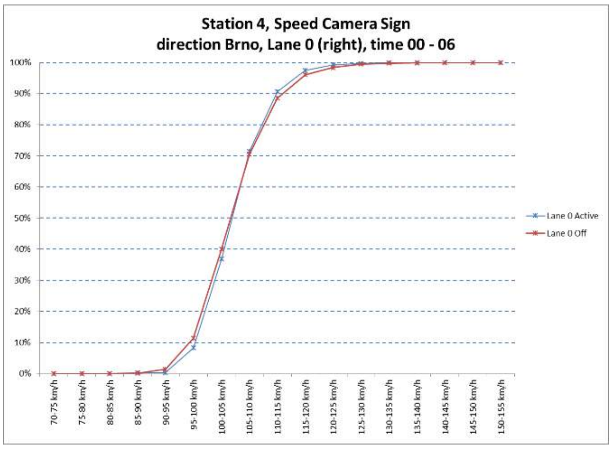
Table 18: Mean speeds and standard deviations speed camera sign (detector 4), divided by time of the day (00-06, 06-12, 12-18 and 18-24)

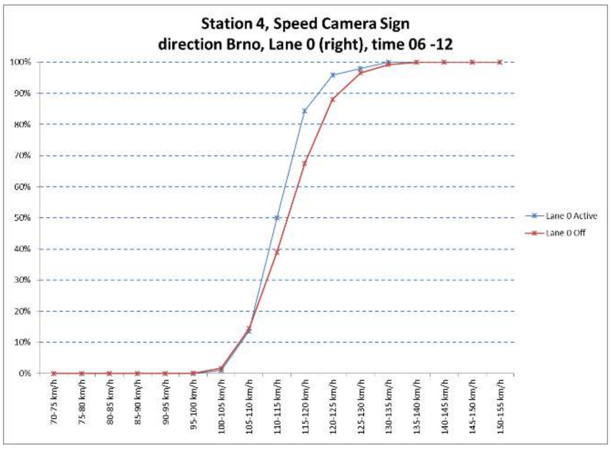
Direction	Lane	DayPeriod	Speed Camera Sign	N	Mean	Mean difference	Std. Deviation	Std difference
Brno	Right	00 - 06	off	3 707	102,2		6,7	
			Active	279	102,4	0,1	5,9	-0,8
		06 - 12	off	2 014	112,2		6,6	
			Active	96	110,3	-1,9	5,3	-1,3
		12 - 18	off	1 471	111,6		5,4	
			Active	42	104,7	-6,9	5,3	-0,1
		18 - 24	off	3 080	110,5		6,6	
			Active	223	107,6	-2,9	5,1	-1,5
	Left	00 - 06	off	3 335	116,2		11,4	
			Active	232	113,9	-2,3	10,1	-1,3

		06 - 12	off	3 594	127,0		7,1	
			Active	279	122,2	-4,8	5,8	-1,2
		12 - 18	off	2 905	124,0		5,7	
			Active	252	118,0	-5,9	5,4	-0,3
		18 - 24	off	3 421	124,6		7,6	
			Active	270	120,3	-4,3	6,8	-0,7

In **Figure 59** and **Figure 60**, the speed distributions are shown for speed camera sign, direction to Brno. For the right lane, direction to Prague, the results are also presented divided in 4 time periods (00-06, 06-12, 12-18 and 18-24). From the figures it can be concluded that the speed distribution is shifted to the left, indicating a better speed compliance and lower mean speeds when the speed camera sign is active.







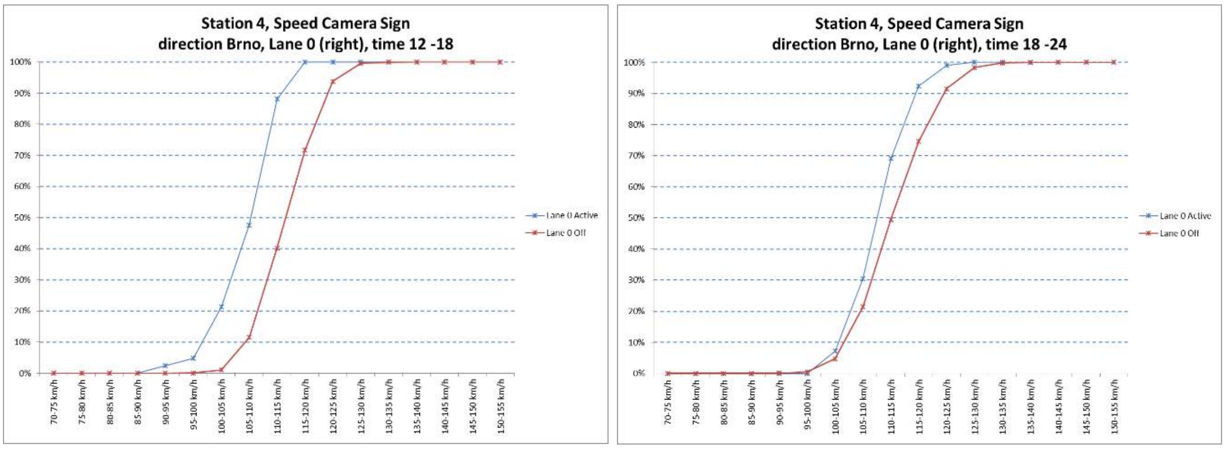


Figure 59: Speed distributions, right lane, and speed camera sign direction to Brno

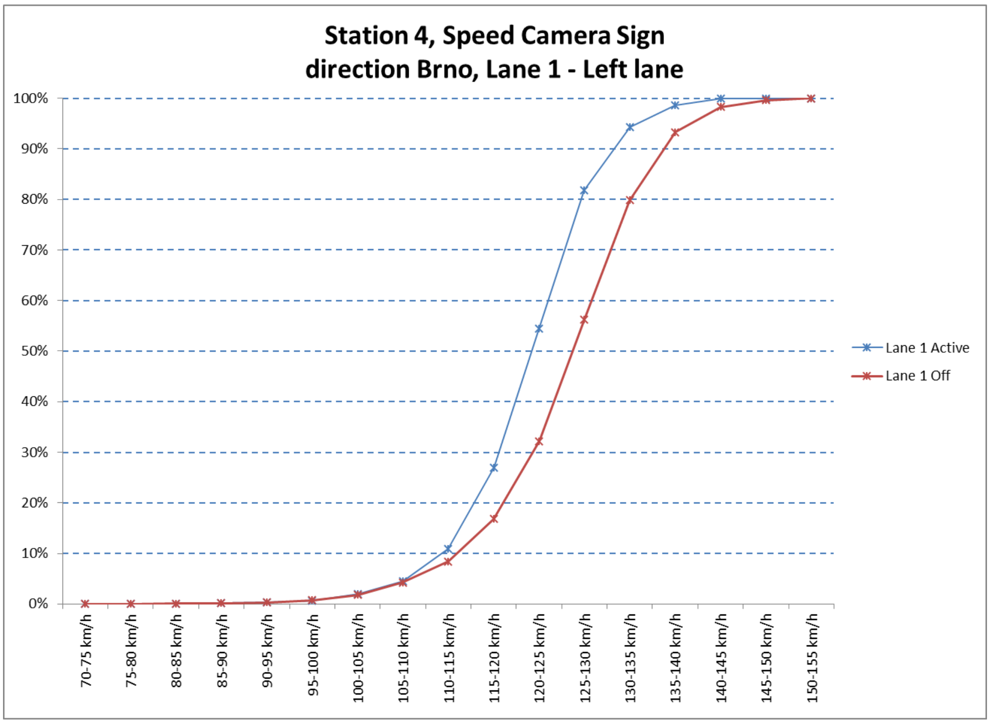


Figure 60: Speed distributions, left lane, and speed camera sign direction to Brno

3.5.1.5 Conclusions and perspectives

Activities carried out along the D1 motorway have been a great opportunity to test some of the interesting measures identified during the first half of the ASAP project. Consequent resources have been used and as illustrated along the previous chapters positive effects have been observed with some of the measures. However new questions also arise, typically about deployment aspects. Quite few comprehensive speed monitoring campaigns at road works have been reported in a European context. The ASAP D1 showcase contributes filling this gap and illustrates important deployment issues.

Looking back at the effect the speed management measures have had on speed behavior it appears that the use of a speed camera sign in the advance warning area clearly impacts driven speeds (-2,5 km/h to -4 km/h). A penalty point system being in use in CZ, drivers are afraid of possible speed control (that can only be done by the Police) and are likely elicited to reduce their speed as they expect police patrol to be present. One should also notice that the sign was used for the first time on motorway WZ in the framework of this showcase.

Other measures seemed to also influence the driving speed behavior, but to a lower extend (i.e. up to -2,5 km/h) In general were mean speeds and standard deviation positively impacted by the VMS trailer (activated by over speeding vehicles) installed in the work zone as well as by the Police car presence.

However the VMS LED trailer installed in the advance warning area didn't seem to significantly impact the driven speed around the transition area (only minor changes were observed for mean speed and standard deviation).

Deploying and maintaining all this equipment has been (and remains) a challenge, as discussed later in chapter 4. One important element with such speed monitoring campaigns is linked to the location of the speed detectors. As far as possible their location should be fixed by monitoring needs only; i.e. located where it is interesting to measure speed to be able to evaluate the spatial effectiveness of the speed management measure, and not where e.g. a support pole or power supply is present. This is an important deployment issue that must be considered for all further implementation activity.

Particularly site constraints impacted the location of the speed monitoring devices and speed management measures during the D1 showcases in such a way that the distance between the tested measure and the nearby detector was sometime long (up to 1300m). This may be a reason why we didn't measure significant changes with some measures (e.g. VMS LED trailer in the advance warning area).

Perspectives for further work

- Confirm the effect of the speed camera sign and particularly investigate its spatial and temporal effectiveness, combined (or not) with police patrol presence;
- Look for additional cooperation with Police department to further investigate the impact of the presence of Police patrol on site;
- Further study the impact of (repeated) speed activated signs and VMS; ideally in combination with license plate recognition and/or Police presence/controls;
- Repeat speed monitoring campaigns with a VMS LED trailer used in the advance warning area, as this measure is still expected to provide a great potential to warn drivers about the temporary traffic management measures and potentially about speed control actions.

3.5.2 Belgium – Motorway A15/E42, section Daussoulx-Sambreville

3.5.2.1 Introduction

Several results are presented in the following sub-chapters. They are all based on individual vehicle speed data aggregated on a 5 minutes time interval and processed following the method described in the chapter 3.3.6. These datasets are hereafter identified as the “5’ mean speed filtered data”.

Preliminary remark: the following sections mainly focus on a comparison site by site, i.e. looking at the speed behavior across the monitoring periods, and not on a comparison of the speed behavior between the monitoring locations. Indeed, one should be careful when comparing traffic behavior between the monitoring sites because the installation conditions of the sensor (that influence the speed measurement) may be slightly different from site to site.

As presented in the chapter 3.4.2.3 four test periods have been defined based on the periods the automatic speed camera was on site and on the speed data availability:

- Period 1 is from 08/04 to 29/04/2014 and is characterized by the presence of an automatic speed camera at KP48,25;
- Period 2 is from 29/04 to 06/05/2014 and corresponds to the “base/reference situation” i.e. with the signing scheme used all along road works period (as described in chapter 3.4.2.1);
- Period 3 is from 06/05 to 13/05/2014 and is characterized by the presence of an automatic speed camera at KP55,6 (along the shoulder lane temporarily opened to the regular traffic);
- Period 4 is from 13/05 to 15/06/2014 and corresponds again to the “base/reference situation”.

Speed and traffic were monitored at four locations (more details in chapter 3.4.2.2):

- Along the shoulder lane temporarily opened to the regular traffic at KP 57,35;
- Along the shoulder lane temporarily opened to the regular traffic at KP 59,35;
- Along the contraflow lane temporarily opened to the regular traffic at KP 53,3;
- 200 m before the crossing of the central reserve, i.e. along the two adjacent lanes, at KP 49,1.

Consequently the following parameters have been calculated for each speed monitoring sites and for each period:

- The average of the 5’ mean speeds (“Avg” in the tables and graphs hereafter);
- The 85th Percentile of the 5’ mean speeds (“P85”);
- The Variance of the 5’ mean speeds (“Variance”);
- The relative number of vehicles exceeding the temporary speed limit (“>70km/h”);
- The relative number of vehicles exceeding the temporary speed limit+5km/h (“>75km/h”).

These parameters are first presented, together with speed distributions, for 24 hours’ time periods. However as the traffic conditions and road user behavior may differ depending on the period of the day, both are also presented by 6 hours’ time periods (i.e. 00h to 06h, 06h to 12h, 12h to 18h and 18h to 00h).

3.5.2.2 Results from speed monitoring along the work zone (traffic on the shoulder lane) at KP57.35

This monitoring site was located 8 km downstream the crossing of the central reserve, 9,1 km downstream the Automatic speed camera deployed during Period 1 and 1,75 km downstream the Automatic speed camera deployed during Period 3.

<u>24h time period</u> – Average, P85 & variance of 5 minutes mean speeds

		P1	P2	P3	P4		P1	P2	P3	P4
24h	#datasets	5188	1921	1866	8513					
	Avg	75,5	76,7	75,9	76,6	>70km/h	88,6%	95,3%	90,4%	92,9%
	Variance	24,8	19,9	22,7	24,2	>75km/h	54,4%	66,8%	56,9%	65,0%
	P85	80,1	80,6	80,4	81,0					

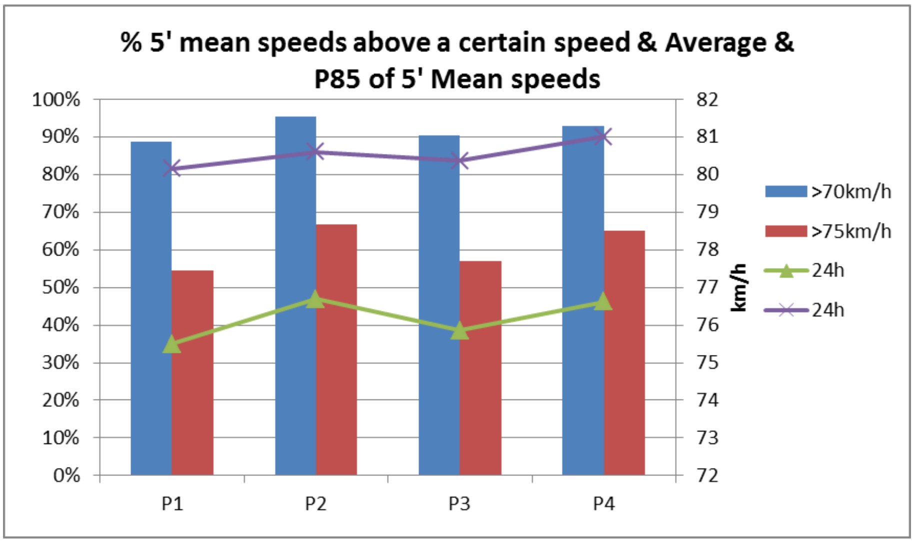


Figure 61: Average, P85 & variance of 5 minutes mean speeds (24h time period; KP57.35)

Following the table and graph on **Figure 61** periods 1 and 3 appear to be characterized by slightly lower Mean speeds. Particularly traffic was during Period 1 around 1 km/h slower (on average) as compared to periods 2 & 4. During periods 2 & 4, a higher proportion (4 to 7%) of drivers was driving above the temporary speed limit than during Period 1.

Soon during the data analysis it appeared that the period of the day is an important factor when looking at speed behavior and that speed amplitudes between different periods of the day may be higher that between the showcase periods (1 to 4). The analysis has therefore been repeated by 6 hours' time periods. The results are presented hereafter.

<u>6h time periods</u> – Average, P85 & variance of 5 minutes mean speeds

		P1	P2	P3	P4		P1	P2	P3	P4
00h-->06h	#datasets	1313	492	485	2135					
	Avg	79,4	79,9	79,8	80,0	>70km/h	97,6%	98,0%	99,2%	97,7%
	Variance	23,9	25,4	20,5	26,0	>75km/h	83,5%	85,8%	87,2%	86,7%
	P85	84,1	84,7	84,4	84,9					
06h-->12h	#datasets	1291	479	499	2141					
	Avg	73,2	75,4	73,9	75,2	>70km/h	78,2%	92,5%	84,0%	90,1%
	Variance	22,6	17,4	16,3	20,5	>75km/h	33,3%	57,0%	36,9%	52,9%
	P85	77,3	79,0	77,4	78,8					
12h-->18h	#datasets	1276	478	461	2116					
	Avg	73,3	74,7	73,3	74,4	>70km/h	82,8%	92,9%	84,8%	89,1%
	Variance	14,4	10,0	11,8	16,0	>75km/h	35,6%	51,0%	34,5%	47,1%
	P85	76,8	77,6	76,4	77,8					
18h-->00h	#datasets	1308	472	421	2121					
	Avg	76,0	76,7	76,5	76,9	>70km/h	95,6%	97,7%	94,1%	94,8%
	Variance	12,3	10,3	14,5	15,5	>75km/h	64,4%	72,9%	70,3%	73,4%
	P85	79,3	79,6	80,1	80,4					

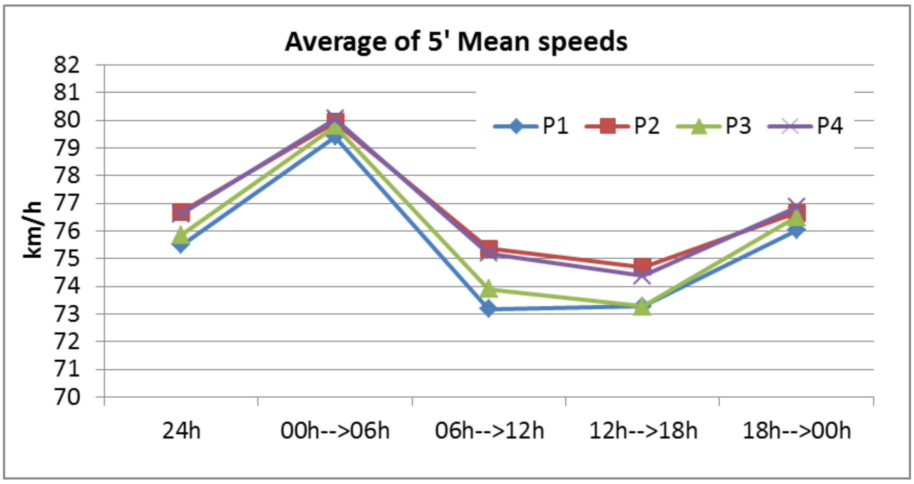


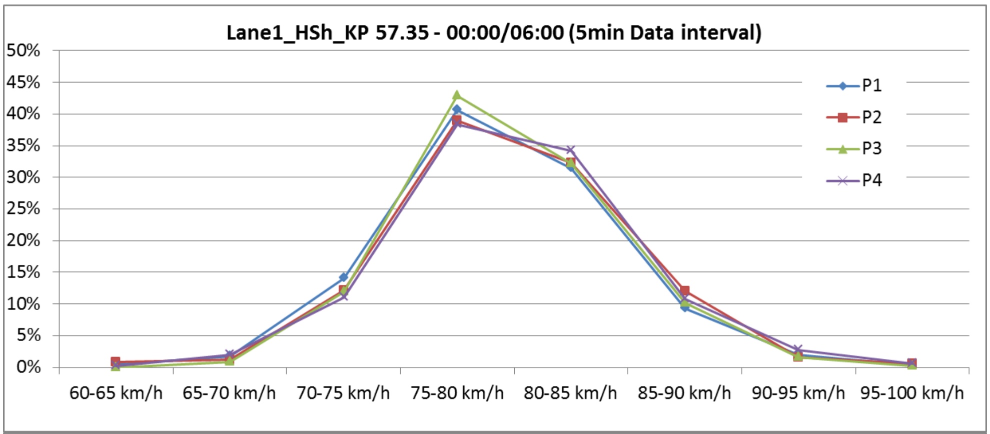
Figure 62: Average, P85 & variance of 5 minutes mean speeds (6h time periods; KP57.35)

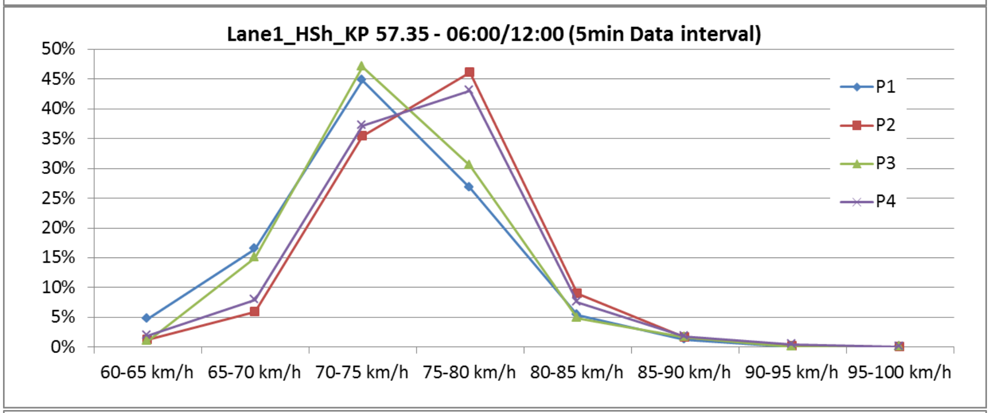
Figure 62 here above interestingly shows that:

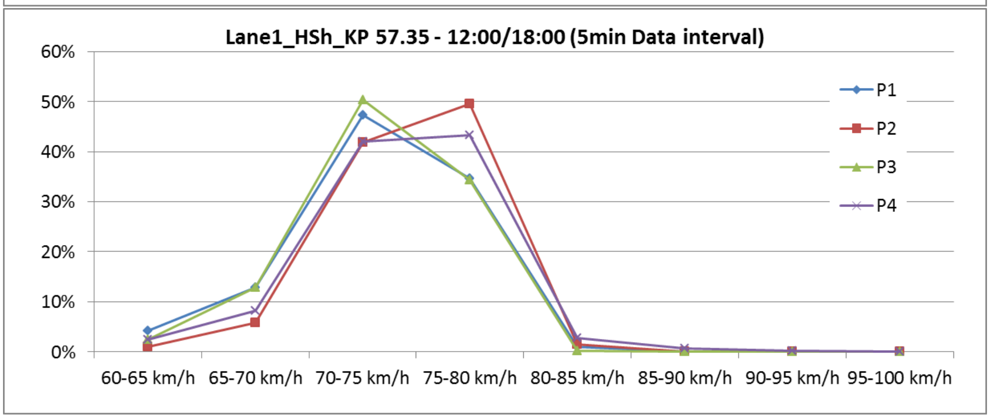
- higher speeds were recorded in night time: the average 5' mean speed ranges from around 80km/h for the 00h-06h time period to 73/74 km/h for the 12h-18h time period;
- lower speeds are recorded from 06h till 18h;
- the speed difference across the four monitoring periods is much lower for the 00h-06h and 18h-00h time periods than between 06h and18h. This is particularly evident when looking at the proportion of drivers exceeding the temporary speed limit: a weak difference (2 to 4%) for periods between 18h & 06h but a higher proportion (10 to 14%) of drivers driving below the temporary speed limit during Period 1 for periods between 06h & 18h.

This last result is also clearly visible in the four following graphs (**Figure 63**) that show the speed distribution by 5 km/h classes (cumulative distributions are presented in appendix 3).

<u>6h time periods</u> – Speed distributions (00h - 06h; 06h - 12h; 12h – 18h; 18h – 24h)







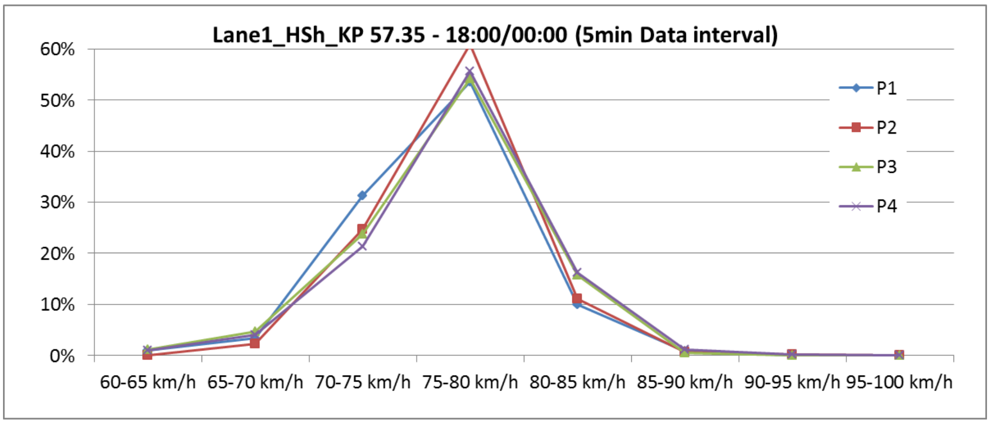


Figure 63: Speed distributions of 5 minutes mean speeds (6h time periods; KP57.35; Lane1_HsH = traffic shifted to the shoulder lane)

Between 00h and 06h and during the evening the speed behavior is very similar across the 4 monitoring periods, independently of the presence of the speed camera (at least where the speed has been monitored).

The graphs here above indicate that in daytime (and where the speed has been monitored), i.e. between 06h and 18h, the speed profiles recorded for Periods 1 and 3 (i.e. when a speed camera was installed) clearly differ from the ones related to the two other Periods (base/reference situation).

The traffic flow, the road works activity level and the subjective risk level associated to the road users and road workers safety are likely to be part of the explaining factors for these differences across the time periods.

3.5.2.3 Results from speed monitoring along the work zone (traffic on the shoulder lane) at KP59.35

This monitoring site was located 10 km downstream the crossing of the central reserve, 11,1 km downstream the Automatic speed camera deployed during Period 1 and 3,75 km downstream the Automatic speed camera deployed during Period 3.

When analyzing these results one should remind that the monitoring point is located around 400m upstream of a bridge where the lane width was further reduced and the traffic channelized by a temporary safety barrier. This situation may have impacted the traffic flow.

<u>24h time period</u> – Average, P85 & variance of 5 minutes mean speeds

		P1	P2	P3	P4
24h	#datasets	5269	1931	1942	6603
	Avg	77,4	78,1	77,5	77,6
	Variance	23,3	20,8	19,9	21,7
	P85	81,7	81,9	81,4	81,7

	P1	P2	P3	P4
>70km/h	93,8%	96,1%	96,0%	95,4%
>75km/h	73,3%	81,1%	73,3%	75,4%

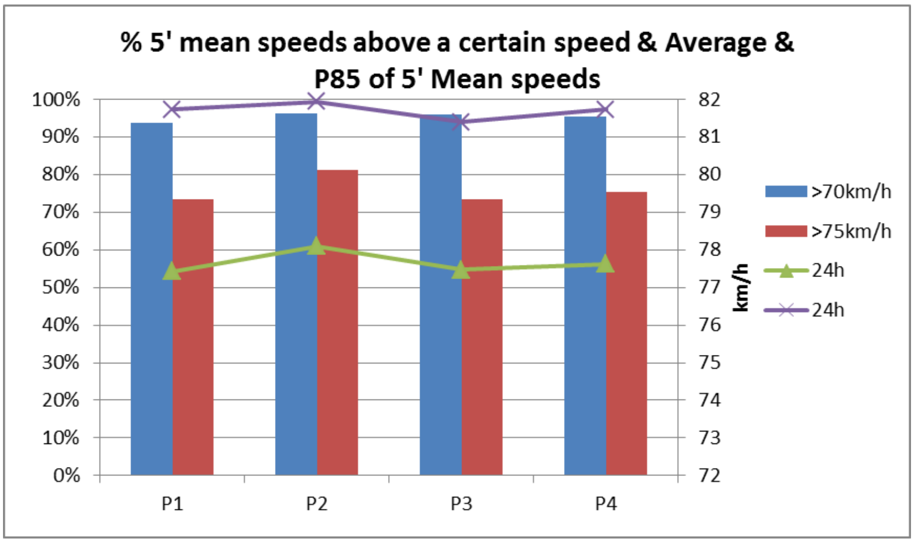


Figure 64: Average, P85 & variance of 5 minutes mean speeds (24h time period; KP59.35)

Differently than on KP 57.35 the table and graph on **Figure 64** shows that on KP59.35 the speed behavior was very similar across the four monitoring periods (very week differences from P1 to P4). Only Period 2 seems to slightly differ from the three other periods. Like for KP 57.35 the analysis has been repeated by 6 hours' time periods.

<u>6h time periods</u> – Average, P85 & variance of 5 minutes mean speeds

		P1	P2	P3	P4		P1	P2	P3	P4
00h-->06h	#datasets	1333	490	490	1657					
	Avg	80,6	81,1	80,8	80,3	>70km/h	97,9%	98,6%	99,0%	97,1%
	Variance	25,3	26,1	23,5	27,7	>75km/h	87,9%	91,8%	90,2%	87,6%
	P85	85,4	86,1	85,0	85,2					
06h-->12h	#datasets	1303	485	496	1649					
	Avg	75,2	76,7	76,0	76,1	>70km/h	86,9%	93,6%	94,2%	92,5%
	Variance	23,4	19,2	14,4	20,0	>75km/h	55,2%	69,1%	64,3%	63,2%
	P85	79,4	80,5	79,1	79,9					
12h-->18h	#datasets	1307	468	480	1622					
	Avg	75,9	76,6	75,5	76,2	>70km/h	93,1%	94,9%	95,8%	95,4%
	Variance	13,7	11,0	9,5	12,9	>75km/h	65,6%	79,9%	61,3%	69,2%
	P85	79,4	79,8	78,4	79,2					
18h-->00h	#datasets	1326	488	476	1675					
	Avg	77,9	77,8	77,5	77,8	>70km/h	97,1%	97,1%	95,2%	96,6%
	Variance	13,0	13,5	15,5	14,9	>75km/h	84,0%	83,6%	77,5%	81,6%
	P85	81,1	81,0	81,2	81,3					

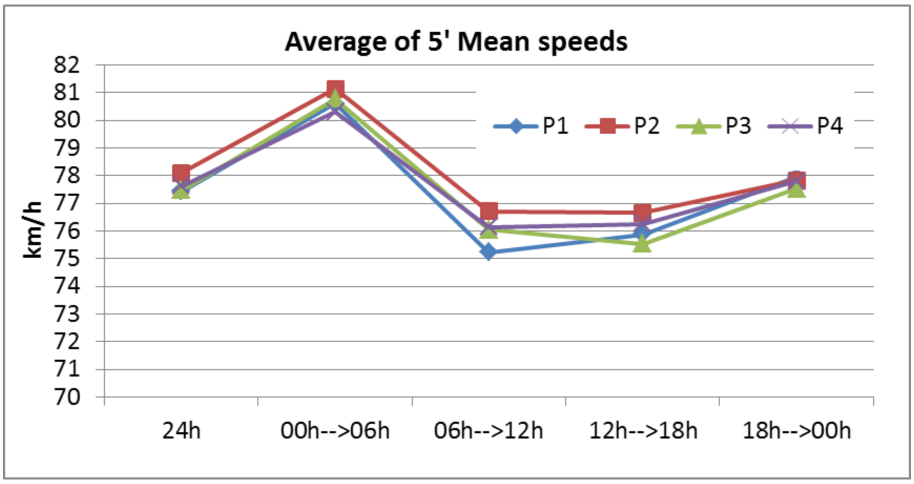


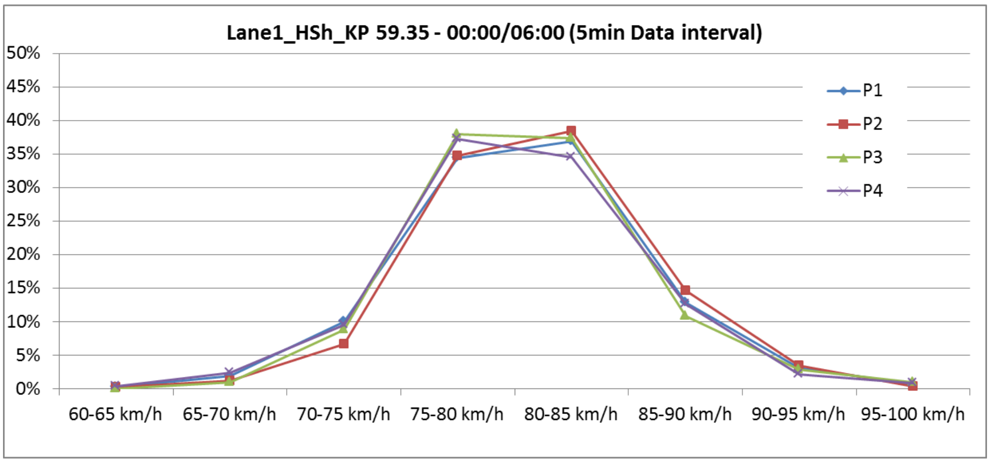
Figure 65: Average, P85 & variance of 5 minutes mean speeds (6h time periods; KP59.35)

Like for KP 57.35 **Figure 65** shows that:

- higher speeds were recorded in night time: the average 5' mean speed ranges between 80 and 81km/h for the 00h-06h time period to around 76 km/h for the 12h-18h time period;
- lower speeds are recorded from 06h till 18h;
- the speed difference across the four monitoring periods is lower for the 00h-06h and 18h-00h time periods than between 06h and18h. Looking at the proportion of drivers exceeding the temporary speed limit shows a small difference (around 2%) for periods between 18h & 06h and a little higher proportion (3 to 7%) of drivers driving below the temporary speed limit during Period 1 for periods between 06h & 18h.

This last result is also clearly visible in the four following graphs that show the speed distribution by 5 km/h classes (cumulative distributions are presented in appendix 3).

<u>6h time periods</u> – Speed distributions (00h - 06h; 06h - 12h; 12h – 18h; 18h – 24h)



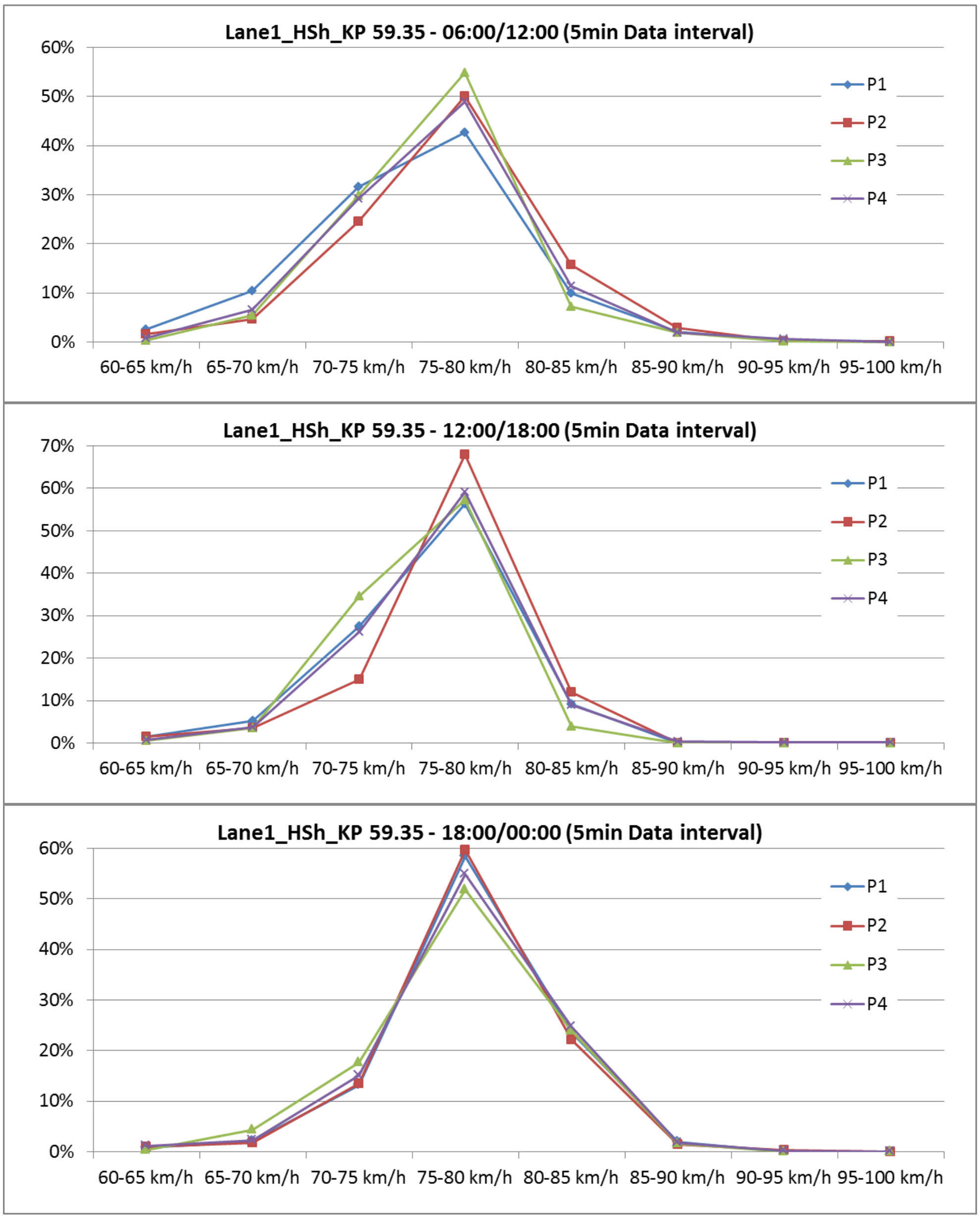


Figure 66: Speed distributions of 5 minutes mean speeds (6h time periods; KP59.35; Lane1_HsH = traffic shifted to the shoulder lane)

Graphs on **Figure 66** indicate that daytime speed profiles, i.e. between 06h and 18h, present more differences across the four monitoring periods than in evening and nighttime. However it is more difficult to drawn clear trends for this monitoring location than for the one located at KP57,35.

3.5.2.4 Results from speed monitoring along the contraflow lane at KP53.3

This monitoring site was located 4 km downstream the crossing of the central reserve and 5 km downstream the Automatic speed camera deployed during Period 1.

This site is not concerned by the Automatic speed camera deployed during Period 3.

<u>24h time period</u> – Average, P85 & variance of 5 minutes mean speeds

		P1	P2	P3	P4		P1	P2	P3	P4
24h	#datasets	4713	1842	1860	8215					
	Avg	78,5	80,1	78,6	76,5	>70km/h	91,0%	94,8%	91,6%	83,1%
	Variance	72,1	65,6	71,6	58,3	>75km/h	60,3%	72,5%	61,6%	50,2%
	P85	86,3	88,0	86,8	84,0					

Following the table above Period 4 appear to be characterized by a lower Mean speeds than during Periods 1 to 3. However this phenomenon can't be explained by any change in the road and traffic conditions. The only event that happened during period 4 is an operation on the radar sensor; i.e. device removal, battery loading and device installation. This operation executed at the beginning of the 7th monitoring week (Period 4 is composed of weeks 6 to 10) may have impacted the accuracy of the detection system (a Doppler radar being very sensitive to the installation conditions).

Therefore in the next table and graphs Period 4 is only represented by measurements from 6th week. Based on the analysis of the datasets this is supposed to better represent the speed behavior during the fourth period.

		P1	P2	P3	P4 (w6)		P1	P2	P3	P4 (w6)
24h	#datasets	4713	1842	1860	1862					
	Avg	78,5	80,1	78,6	78,3	>70km/h	91,0%	94,8%	91,6%	89,4%
	Variance	72,1	65,6	71,6	67,9	>75km/h	60,3%	72,5%	61,6%	57,9%
	P85	86,3	88,0	86,8	86,8					

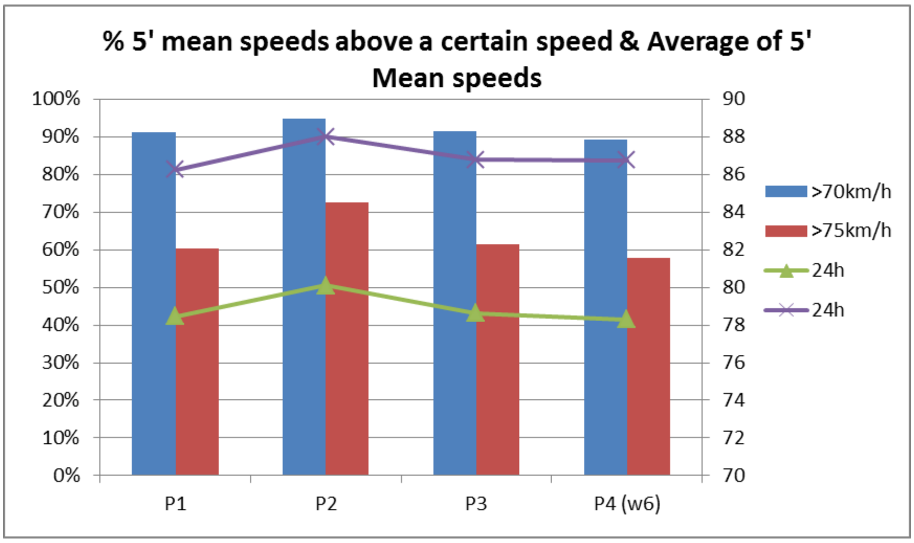


Figure 67: Average, P85 & variance of 5 minutes mean speeds (24h time period; KP53.3)

Table and graph on **Figure 67** show that on KP53.3 the speed behavior was very similar across the four monitoring periods (very week differences from P1 to P4). Only Period 2 seems to slightly differ from the three other periods.

Like for the two other monitoring sites the analysis has been repeated by 6 hours' time periods. The results are presented hereafter.

6h time periods – Average, P85 & variance of 5 minutes mean speeds

		P1	P2	P3	P4 (w6)		P1	P2	P3	P4 (w6)
00h-->06h	#datasets	1063	430	444	431					
	Avg	87,2	87,9	87,3	87,0	>70km/h	98,7%	98,1%	99,3%	99,1%
	Variance	106,9	89,0	85,5	70,4	>75km/h	93,2%	94,7%	95,0%	95,4%
	P85	96,1	96,8	96,3	95,4					
06h-->12h	#datasets	1237	471	480	465					
	Avg	75,0	76,8	74,7	74,1	>70km/h	84,9%	91,1%	83,3%	79,4%
	Variance	34,9	38,9	40,5	34,3	>75km/h	41,6%	57,1%	41,3%	34,2%
	P85	80,2	82,6	78,4	78,3					
12h-->18h	#datasets	1203	483	472	489					
	Avg	74,0	75,6	73,6	73,1	>70km/h	86,9%	92,3%	87,9%	81,6%
	Variance	14,9	16,6	13,3	17,2	>75km/h	37,7%	53,6%	34,1%	28,0%
	P85	77,3	79,7	76,6	76,8					
18h-->00h	#datasets	1225	463	469	482					
	Avg	78,7	80,8	79,4	79,8	>70km/h	94,6%	98,1%	96,4%	98,1%
	Variance	38,5	32,7	35,9	35,7	>75km/h	72,2%	87,3%	78,3%	77,2%
	P85	84,7	87,0	85,2	85,8					

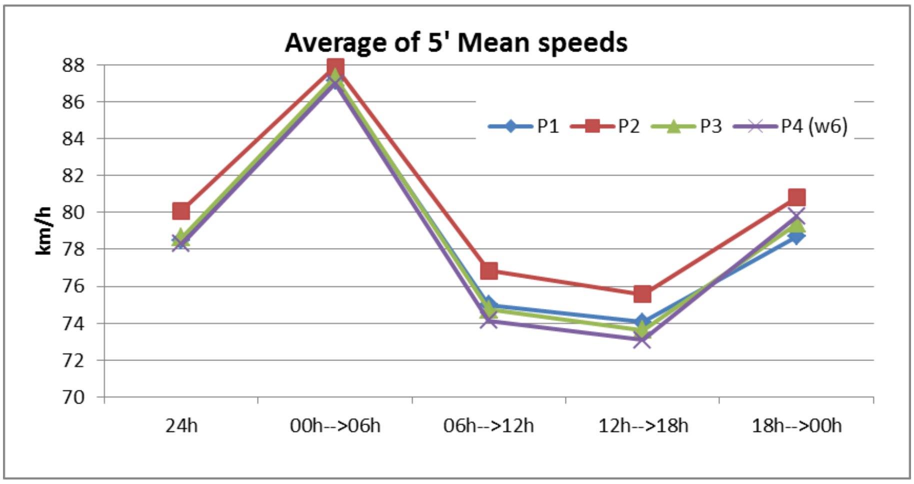


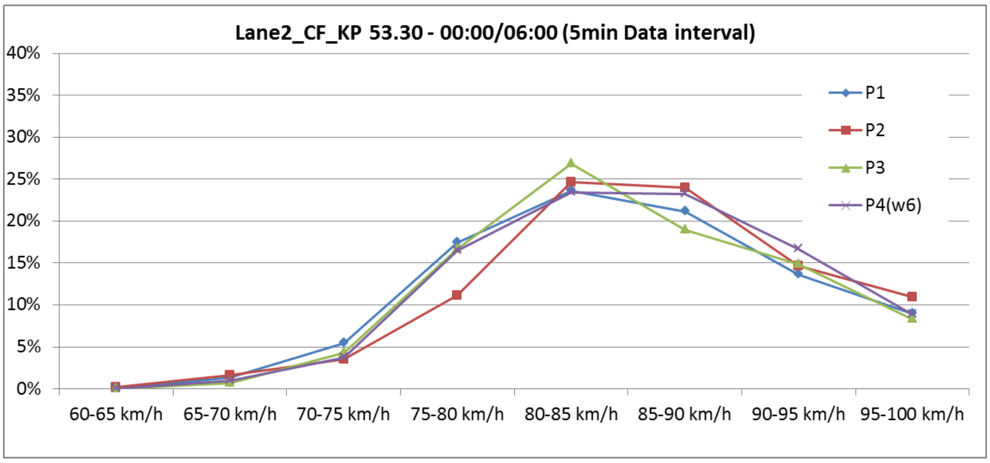
Figure 68: Average, P85 & variance of 5 minutes mean speeds (6h time periods; KP53.3)

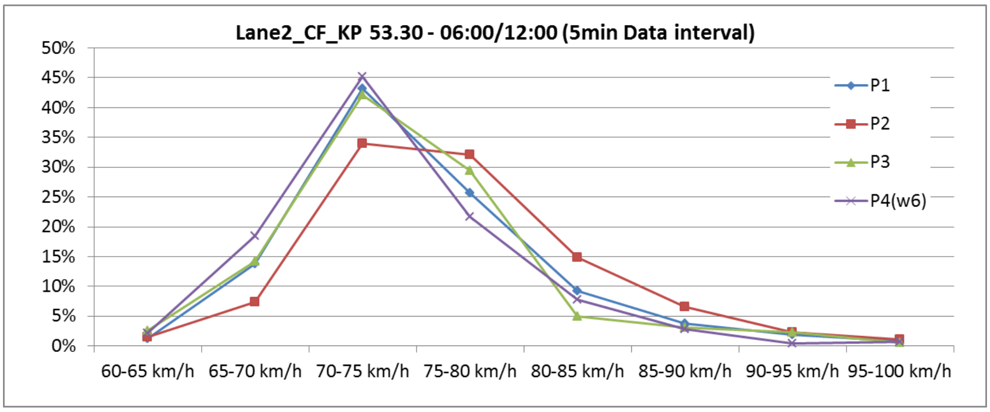
Figure 68 indicates that:

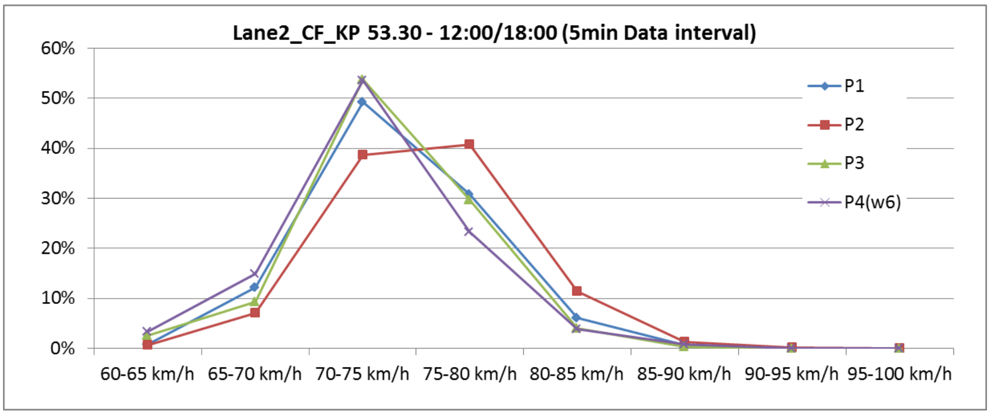
- higher speeds were recorded in night time: the average 5’ mean speed ranges between 87km/h for the 00h-06h time period to around 74 km/h for the 12h-18h time period;
- lower speeds are recorded from 06h till 18h;
- the speed difference across the four monitoring periods is lower for the 00h-06h time period than between 06h and 24h. Looking at the proportion of drivers exceeding the temporary speed limit shows a small difference (around 1,5%) for periods between 18h & 06h and a little higher proportion (around 11%) of drivers driving below the temporary speed limit during Period 1 for periods between 06h & 18h.

This last result is also clearly visible in the four following graphs (**Figure 69**) that show the speed distribution by 5 km/h classes (cumulative distributions are presented in appendix 3).

<u>6h time periods</u> – Speed distributions (00h - 06h; 06h - 12h; 12h – 18h; 18h – 24h)







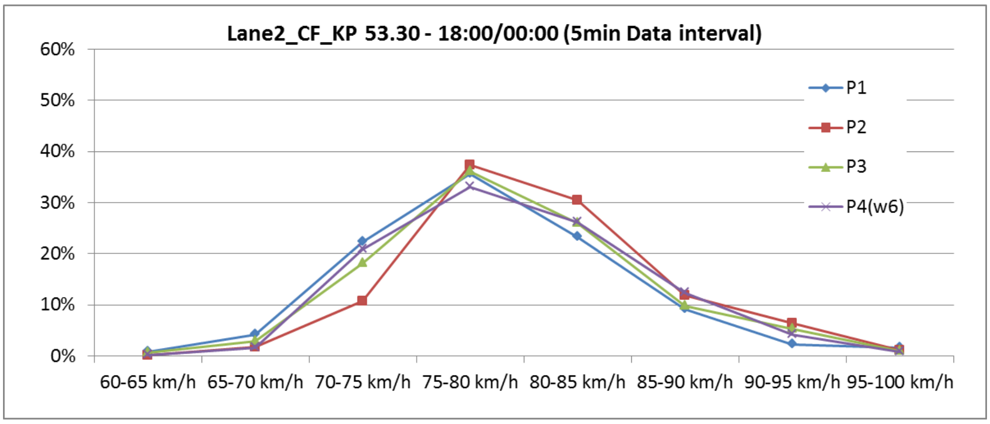


Figure 69: Speed distributions of 5 minutes mean speeds (6h time periods; KP59.35; Lane2_CF = traffic shifted to the contraflow lane)

Between 00h and 06h and during the evening the speed behavior is quite similar across the 4 monitoring periods, independently of the presence of the speed camera during Period 1 (at least where the speed has been monitored).

The graphs here above indicate that daytime speed profiles, i.e. between 06h and 18h, present more differences across the four monitoring periods than in evening and nighttime. These graphs also confirm that higher speeds were registered during the second period, without any evident reasons.

3.5.2.5 Results from speed monitoring upstream of the transition area (limited data sets)

This monitoring site was located 200 m upstream the crossing of the central reserve and 850 m downstream the Automatic speed camera deployed during Period 1. The speed monitoring device was unfortunately not operational during Period 1. As this site is also not concerned by the Automatic speed camera deployed during Period 3 the following results only relate to the speed behavior during periods corresponding to the base/reference situation.

The results are presented hereafter lane by lane.

<u>Right lane - 24h time period</u> – Average, P85, variance of 5 minutes mean speeds & Speed distribution during periods corresponding to the base/reference situation

24h	#datasets	5089		
	Avg	64,0	>70km/h	24,8%
	Variance	88,6	>75km/h	11,0%
	P85	73,0		

CEDR
Conférence Européenne des Directeurs des Routes
Conference of European Directors of Roads

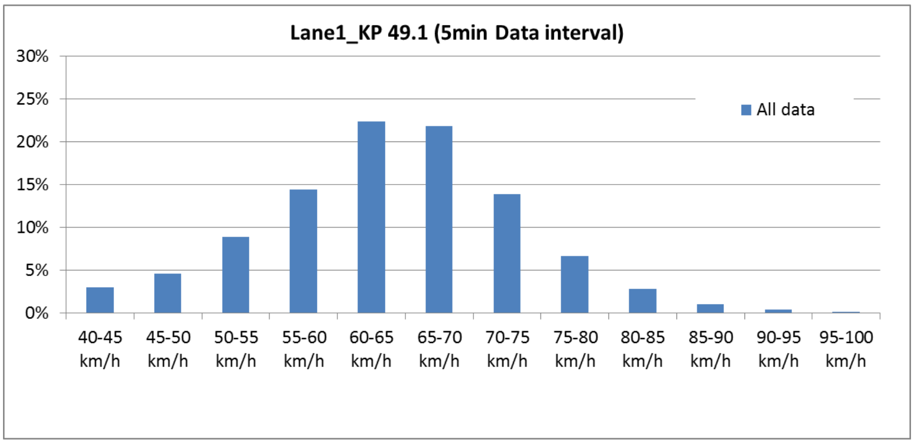


Figure 70: Average, P85, variance of 5 minutes mean speeds & Speed distribution (24h time period; KP49.1; Right lane)

24 hours data show that around 25% of drivers using lane 1 were over speeding (70km/h speed limit) and additionally only 11% exceed 75km/h. This rather small percentage is likely to be explained by the proximity of the transition area (with crossing of the central reserve) combined with the fact that the right lane is more frequently used by truck traffic.

The following graphs and table (**Figure 71**) shows that the speed behavior is also influenced by the period of the day.

<u>Right lane - 6h time periods</u> – Average, P85 & variance of 5 minutes mean speeds during periods corresponding to the base/reference situation

00h-->06h	#datasets	783		
	Avg	62,0	>70km/h	25,4%
	Variance	152,0	>75km/h	14,3%
	P85	74,5		
06h-->12h	#datasets	1363		
	Avg	64,1	>70km/h	20,6%
	Variance	71,0	>75km/h	8,3%
	P85	72,0		
12h-->18h	#datasets	1501		
	Avg	64,5	>70km/h	21,3%
	Variance	53,1	>75km/h	7,2%
	P85	71,6		
18h-->00h	#datasets	1442		
	Avg	64,7	>70km/h	32,2%
	Variance	106,4	>75km/h	15,6%
	P85	75,2		

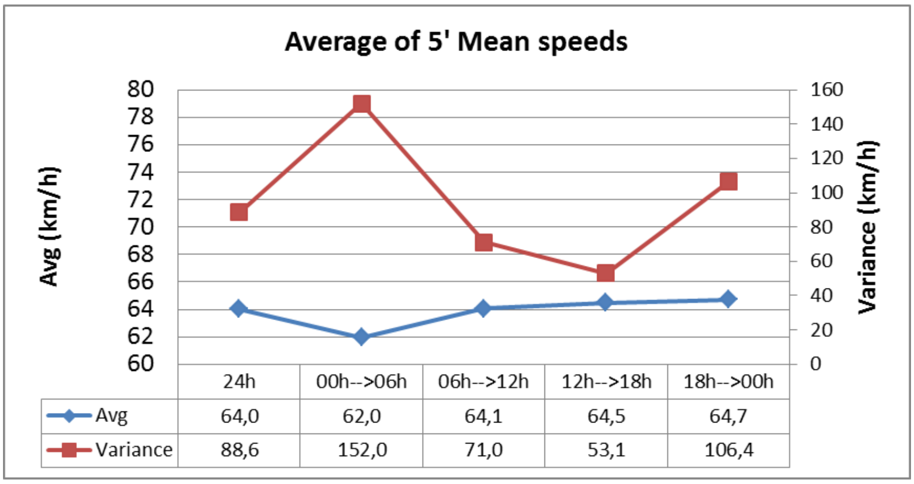
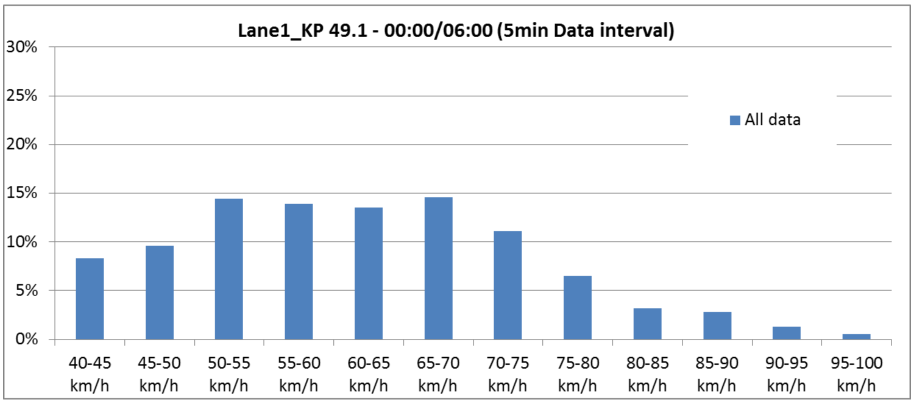
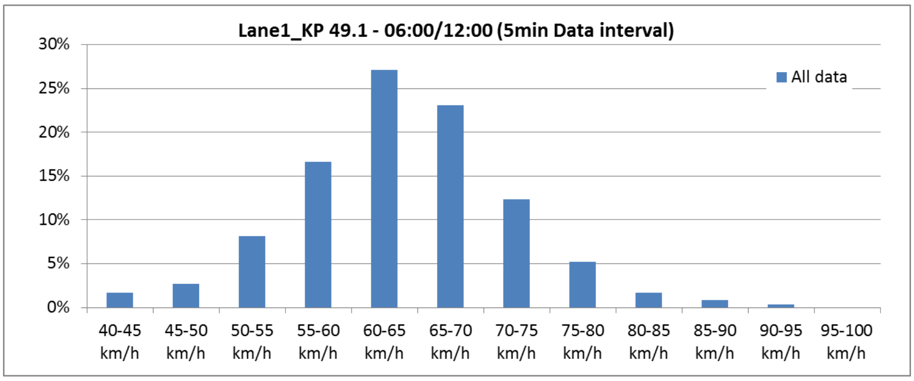


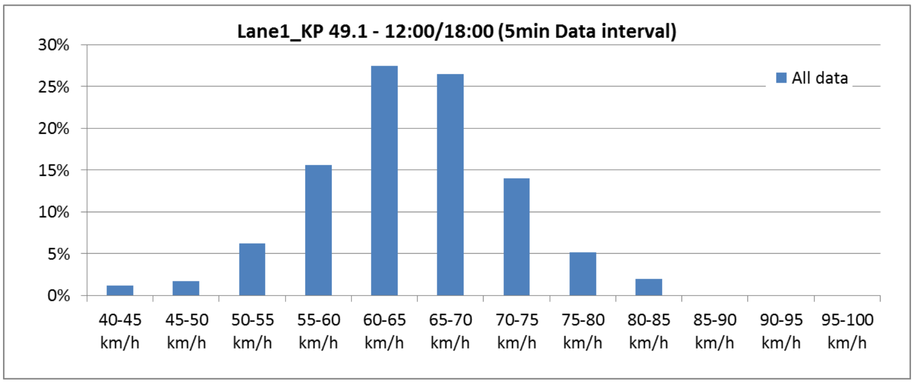
Figure 71: Average, P85, variance of 5 minutes mean speeds (6h time periods; KP49.1; Right lane)

At this location the evening seems to be again more favorable to high speeds, i.e. over speeding increases by 10% from the 12-18h to 18-00h periods. As shown on the following histograms (**Figure 72**) speed distribution also varies across the day and higher speed variances are recorded in night and evening times.

<u>Right lane - 6h time periods</u> – Speed distributions (00h - 06h; 06h - 12h; 12h – 18h; 18h – 24h) during periods corresponding to the base/reference situation







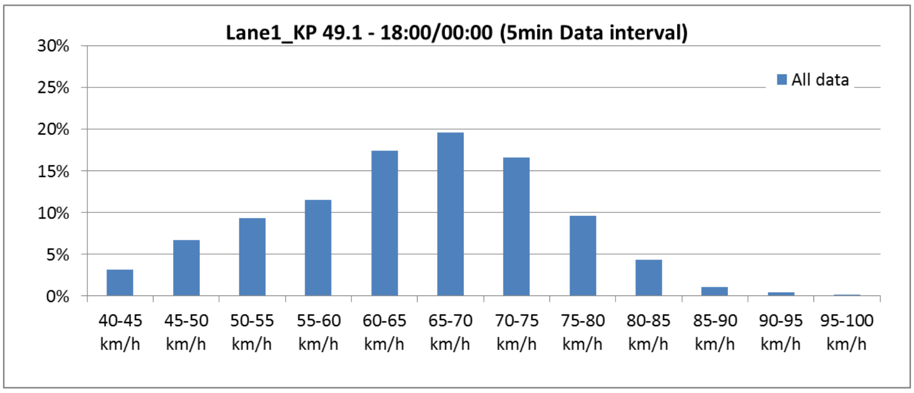


Figure 72: Speed distributions of 5 minutes mean speeds (6h time periods; KP49.1; Right lane)

<u>Left lane - 24h time period</u> – Average, P85, variance of 5 minutes mean speeds & Speed distribution during periods corresponding to the base/reference situation

24h	#datasets	5922		
	Avg	73,5	>70km/h	76,1%
	Variance	33,6	>75km/h	41,0%
	P85	79,0		

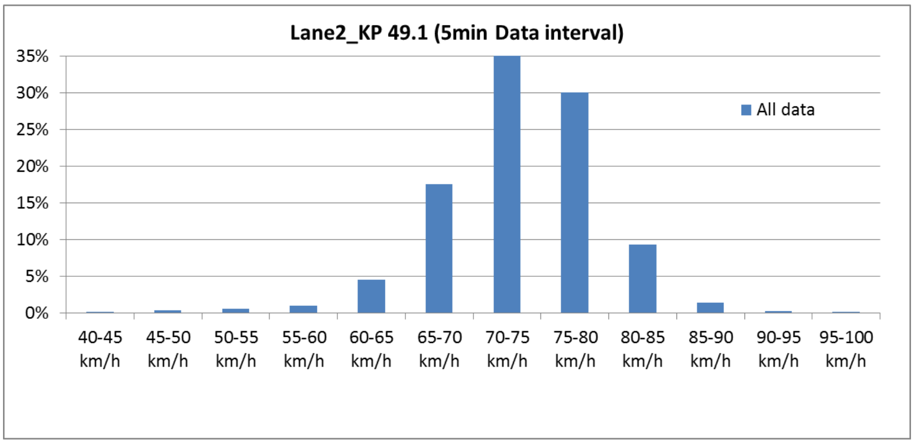


Figure 73: Average, P85, variance of 5 minutes mean speeds & Speed distribution (24h time period; KP49.1; Left lane)

24 hours data (**Figure 73**) show that around 75% of drivers using lane 1 were over speeding (70km/h speed limit) which is 3 times higher than on lane 1. The proximity of the transition area therefore seems to much less influence the traffic behavior on this lane than on the slower one.

The following graphs and table (**Figure 74**) shows that the speed behavior is also influenced by the period of the day.

<u>Left lane - 6h time periods</u> – Average, P85 & variance of 5 minutes mean speeds during periods corresponding to the base/reference situation

00h-->06h	#datasets	1523		
	Avg	77,2	>70km/h	95,2%
	Variance	19,7	>75km/h	70,3%
	P85	81,4		
06h-->12h	#datasets	1377		
	Avg	72,1	>70km/h	64,5%
	Variance	40,6	>75km/h	31,0%
	P85	78,3		
12h-->18h	#datasets	1490		
	Avg	69,9	>70km/h	53,6%
	Variance	25,2	>75km/h	12,8%
	P85	74,6		
18h-->00h	#datasets	1532		
	Avg	74,6	>70km/h	89,4%
	Variance	19,8	>75km/h	48,2%
	P85	78,6		

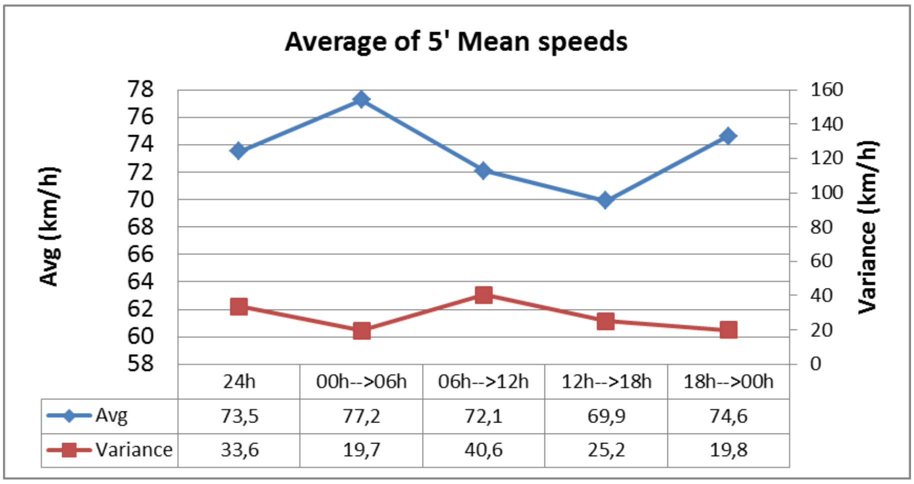


Figure 74: Average, P85, variance of 5 minutes mean speeds (6h time periods; KP49.1; Left lane)

For the left lane the evening seems to also be more favorable to high speeds, i.e. over speeding increases by 30% from the 12-18h to 18-00h periods. As shown on the following histograms speed distribution (**Figure 75**) also varies across the day; lower speed variances being here recorded in night and evening times.

<u>Left lane - 6h time periods</u> – Speed distributions (00h - 06h; 06h - 12h; 12h – 18h; 18h – 24h) during periods corresponding to the base/reference situation

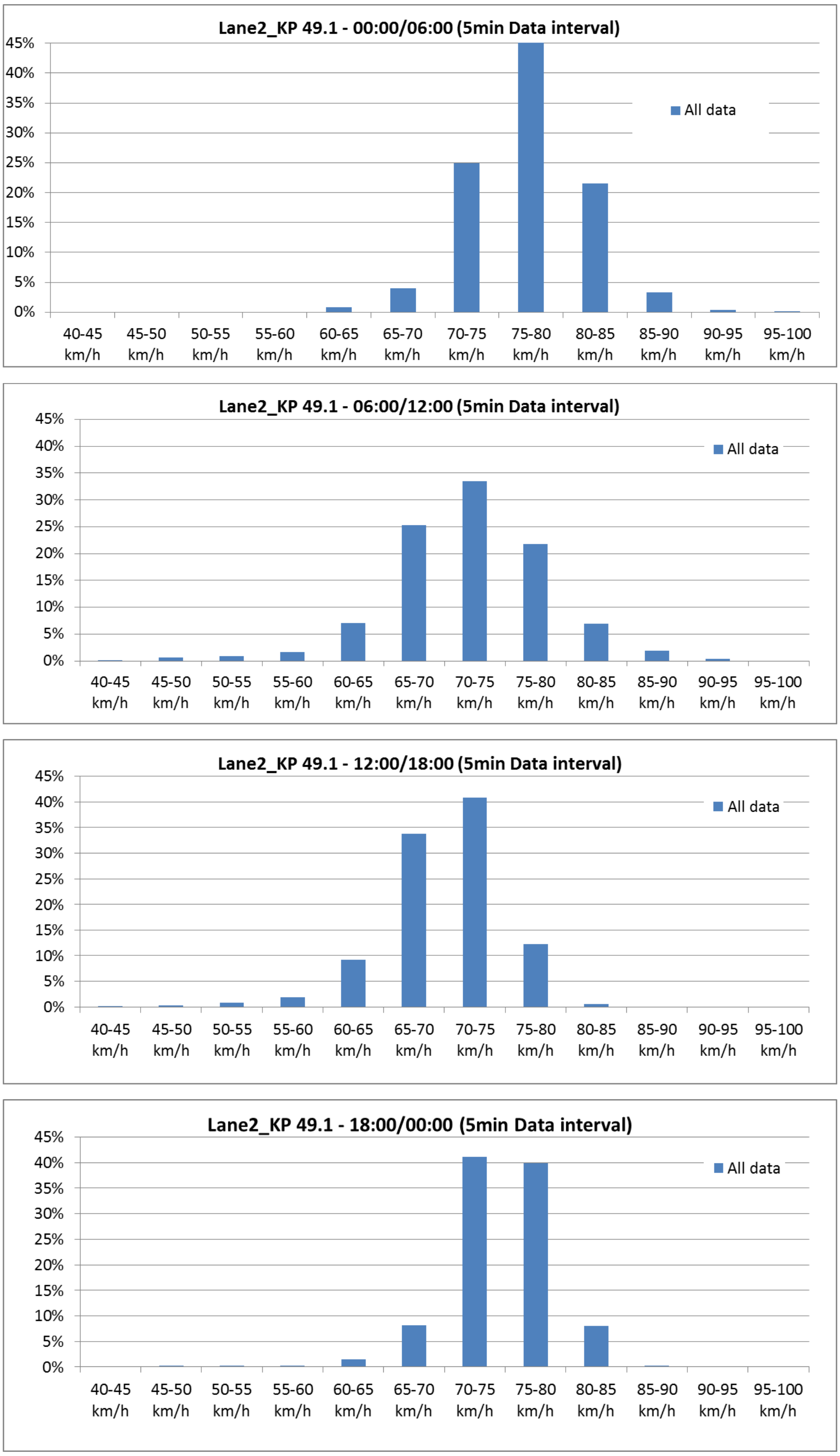


Figure 75: Speed distributions of 5 minutes mean speeds (6h time periods; KP49.1; Left lane)

3.5.2.6 Conclusions and perspectives

The A15/E42 showcase carried out by BRRC mainly consisted in a speed monitoring campaign. In total four devices were installed along the road works to monitor the traffic speed at several locations: a multilane digital wave radar sensor, owned and operated by BRRC, and three portable (single lane) Doppler radars owned and operated by the Walloon road authority.

The location of these devices has been discussed with the project partners and a decision taken considering former experiences, as well as the possible locations for the speed management measures; i.e. the automatic speed camera, the portable speed displays and the trailer with speed/car plate number display. Unfortunately the two latter were finally not available for the testing. Some operational problems also occurred with the BRRC sensor and caused unfortunate gaps in the data sets coming from this device.

Therefore the only measure tested on site, in addition to the signing, equipment and VMS as mentioned in the chapter 3.4.2.1 was the automatic speed camera. As explained in chapter 3.5.2.1 four test periods have been defined based on the periods the automatic speed camera was on site and on the speed data availability. For each period sensor data have been aggregated on a five minutes interval base and filtered to eliminate congestion periods (see the chapter 3.3.6).

The different results presented along the four last sub-chapters lead to the following main conclusions:

- Along the work zone, the recorded speed remains in a reasonable range (as compared to the 70km/h speed limit): mean speed around 76km/h (P85 around 81km/h) on work zone side; around 79km/h (P85 87km/h) along the contraflow lane - completely separated from the Work zone;
- Speed data recorded 200m upstream of the crossing of the central reserve also remain close to the speed limit (higher speeds are however recorded on the left lane) but speed variance at this location is much higher as compared to the other monitoring locations;
- The period of the day is an important factor when looking at speed behavior and speed amplitudes observed between different periods of the day were higher that between the four consecutive monitoring periods (some of these corresponding to speed enforcement periods);
- The analysis based on the 6 hours' time periods confirmed that higher speeds were recorded in night time; with up to 7 km/h and 14 km/h (5 minutes Mean speed average) difference between the 00h-06h and 12h-18h time periods along the work zone and along the contraflow respectively;
- The speed difference across the four monitoring periods is usually lower for the 00h-06h and 18h-00h time periods than between 06h and18h. This seems to indicate the speed management measure has a greater impact on the 06h-18h than between 18h & 06h. Nevertheless this trend remains quite weak and should be confirmed by additional tests. The traffic flow, the road works activity level and the subjective risk level associated to the road users and road workers safety are likely to be part of the explaining factors for these differences across the time periods;
- For one speed monitoring device, i.e. corresponding to the monitoring site that was located 8 km downstream the crossing of the central reserve, 9,1 km downstream the Automatic speed camera deployed during Period 1 and 1,75 km downstream the Automatic speed camera deployed during Period 3, the presence of the Automatic

Speed camera seems to have an impact on the average 5 minutes mean speed and on the proportion of drivers exceeding the temporary speed limit. This is particularly visible for daytime traffic (chapter 3.5.2.2). However this trend is not confirmed on the two other monitoring locations. It is therefore supposed the speed camera has a local impact that decreases when progressing along the RW.

The cooperation with the Road authority has been very positive and much data used in this report comes from devices they installed and operated themselves. Nevertheless, the implementation of this showcase has been a time consuming task that needed a lot of contacts with numerous actors. Once the testing plan decided some interesting monitoring time slots were also missed, sometimes due to communication problems, sometime due to problems with devices. In such monitoring a communication plan is needed at the early stage of the road work planning to identify and commit the various actors. An operational plan is also necessary to schedule the deployment of equipment, to efficiently operate the various devices and organize the data collection.

This first showcase in Belgium already delivers interesting conclusions from which the following perspectives can be drafted.

<u>Perspectives for future work</u>

- Reproduce (a) speed monitoring campaign(s) to confirm the global trends observed; i.e. speed behavior vs time of the day, speed vs traffic volume, higher speed variance at locations close to the transition area, indicators for speed congestion and focus on more homogeneous monitoring periods (duration, traffic characteristics, weather conditions RW activity & configuration).
- Include additional external parameters in the process to better understand the traffic and speed behavior (e.g. activity on the work zone, queuing start and end, weather).
- Continue the evaluation of the effectiveness of the automatic speed camera; i.e. evaluate the spatial & temporal effect by more consistent monitoring periods and successive monitoring locations to confirm and complete the results from the first A15/E42 site.
- Implement and test additional preventive measures like speed displays and dynamic speed warning trailers.
- Coordinate the speed control and speed monitoring from the early planning of the road works project.
- Secure the installation and operational maintenance of the speed & traffic monitoring devices and of the data retrieval.

3.5.3 Belgium - E34/A21 motorway, section Zoersel-Oelegem

3.5.3.1 Introduction

Several results are presented in the following sub-chapters. They are all based on individual vehicle speed data aggregated on a 5 minutes time interval and processed following the method described in the chapter 3.3.6. These datasets are hereafter identified as the "5' mean speed filtered data".

As presented in the chapter 3.4.3.3 speed data were (partially) available for two periods represented by two consecutive road work layouts (stages 1 & 2).

Preliminary remark: the results from speed monitoring during Stage 1 and Stage 2 are hereafter presented together. However it is important to remind that the speed monitoring equipment has been installed on the same location along the whole monitoring campaign; i.e. at KP23.20 and independently of the considered road work stage and temporary traffic management scheme in place.

This means that the distance between the traffic monitoring device used to record speed data and the start of the lane deviation (KP22.95 during Stage 1; KP23.15 during Stage 2) was different from one period to the other (250m & 50m respectively).

The following parameters have been calculated for each speed monitoring sites and for each period:

- The average of the 5' mean speeds ("Avg" in the tables and graphs hereafter);
- The 85th Percentile of the 5' mean speeds ("P85");
- The Variance of the 5' mean speeds ("Variance");
- The relative number of vehicles exceeding the temporary speed limit (">70km/h");
- The relative number of vehicles exceeding the temporary speed limit+5km/h (">75km/h").

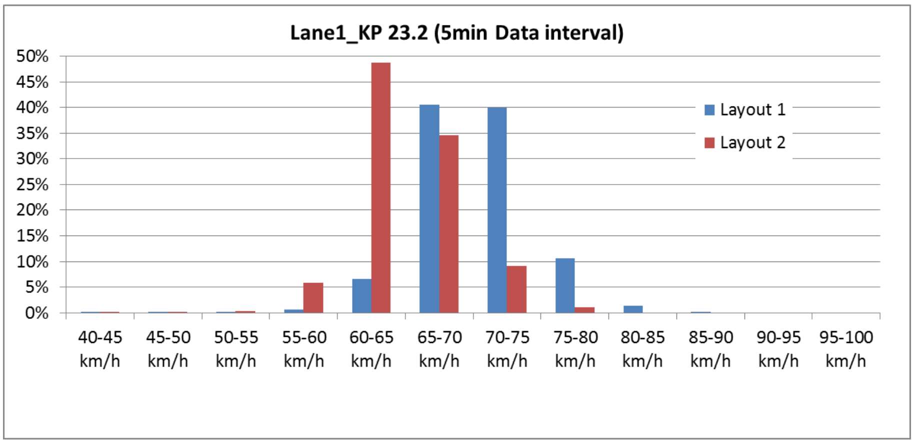
These parameters are first presented, together with speed distributions, for 24 hours' time periods. However as the traffic conditions and road user behavior may differ depending on the period of the day, both are also presented by 6 hours' time periods (i.e. 00h to 06h, 06h to 12h, 12h to 18h and 18h to 00h).

3.5.3.2 Traffic on right lane (KP23.20)

24h time period – Average, P85, variance & speed distribution of 5 minutes mean speeds

	Layout 1	Layout 2
#datasets	3229	1716
Avg	70,4	64,8
Variance	17,0	15,6
P85	74,4	68,7

	Layout 1	Layout 2
>70km/h	52,0%	10,1%
>75km/h	12,0%	1,0%



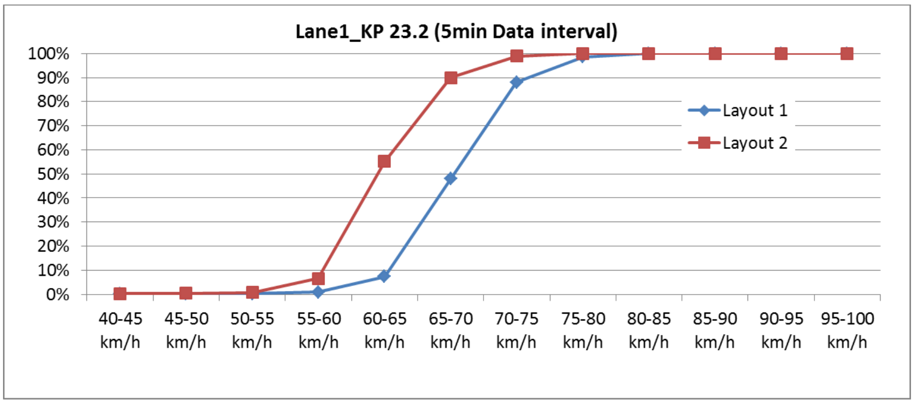


Figure 76: Average, P85, variance & speed distribution of 5 min. mean speeds (24h time period; right lane; KP23.20)

As shown on **Figure 76** driven speed on the right lane seems to be very much influenced by the distance to the lane deviation; the closer is the lane deviation, the slower is the traffic. The second period is also characterized by more homogeneous (5 minutes mean) speeds. Based on the data collected it also appears that the driven speed is quite close to the temporary speed limit.

<u>6h time period – Average, P85 & variance of 5 minutes mean speeds</u>

As on the other Belgian site monitored during the project, the period of the day is an important factor when looking at speed behavior. Table and graph on **Figure 77** shows the speed amplitude between consecutive 6 hours periods.

		Layout 1	Layout 2		Layout 1	Layout 2
00h-->06h	#datasets	789	395			
	Avg	71,4	68,0	>70km/h	60,7%	32,2%
	Variance	17,3	18,1	>75km/h	18,6%	4,3%
	P85	75,5	72,0			
06h-->12h	#datasets	796	407			
	Avg	69,4	63,3	>70km/h	40,5%	3,9%
	Variance	15,8	10,8	>75km/h	6,4%	0,0%
	P85	73,0	66,7			
12h-->18h	#datasets	837	467			
	Avg	69,0	62,6	>70km/h	36,7%	0,0%
	Variance	10,5	8,3	>75km/h	3,3%	0,0%
	P85	72,2	65,1			
18h-->00h	#datasets	807	447			
	Avg	71,9	65,8	>70km/h	70,9%	6,9%
	Variance	18,5	9,3	>75km/h	20,1%	0,2%
	P85	75,8	68,6			

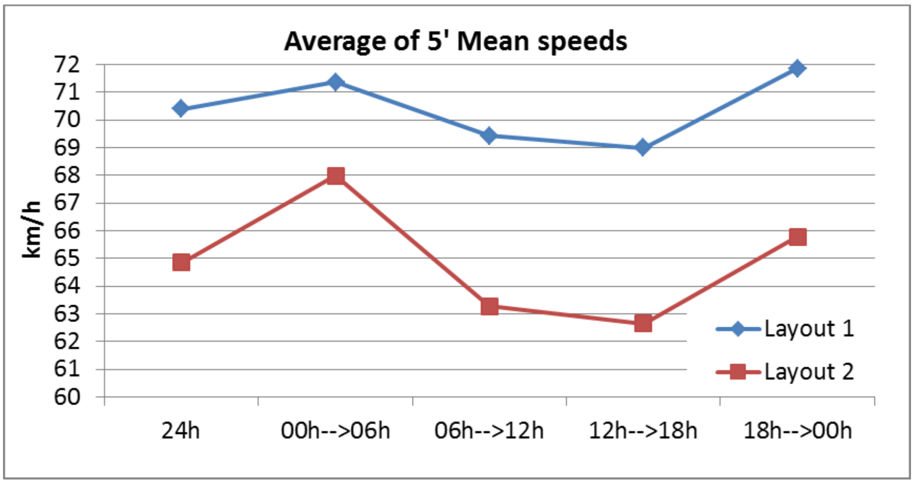


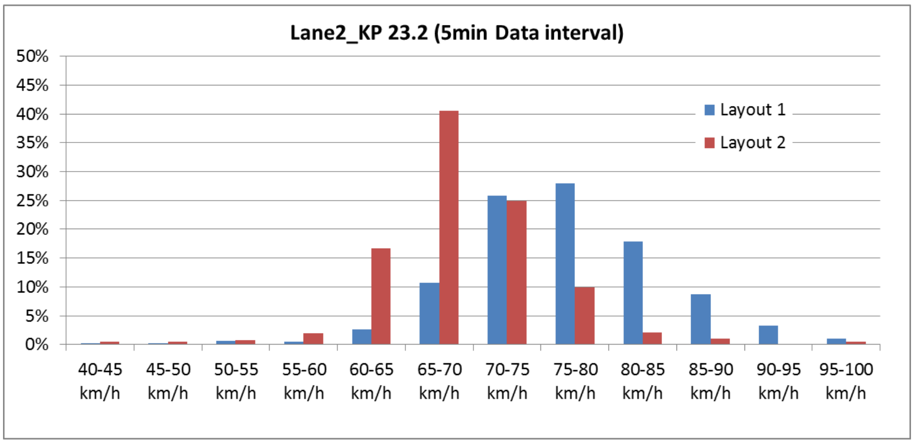
Figure 77: Average, P85 & variance of 5 min. mean speeds (6h time periods; right lane; KP23.20)

Table and graph above interestingly indicate that higher speeds were recorded in night time (from 18h till 06h). The percentage of over speeding vehicles is also bigger during that period.

3.5.3.3 Traffic on left lane (KP23.20)

<u>24h time period</u> – Average, P85, variance & Speed distributions of 5 minutes mean speeds

		Layout 1	Layout 2		Layout 1	Layout 2
24h	#datasets	2622	1338			
	Avg	76,9	69,3	>70km/h	85,0%	39,0%
	Variance	59,8	49,0	>75km/h	59,2%	14,1%
	P85	84,4	74,6			



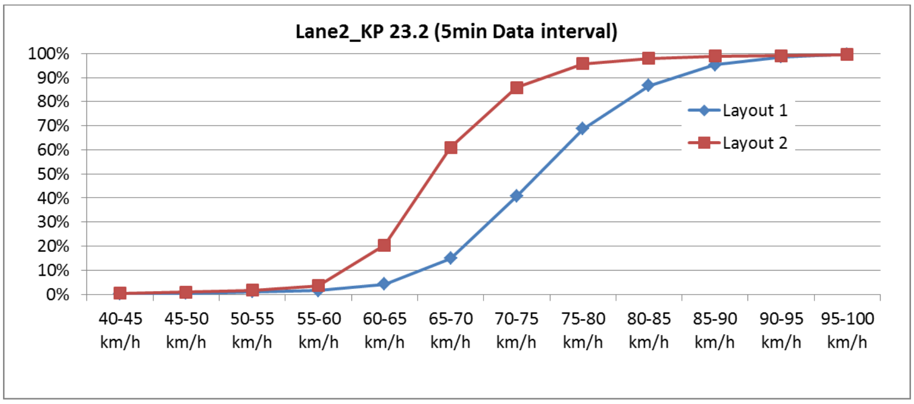


Figure 78: Average, P85, variance & speed distribution of 5 min. mean speeds (24h time period; left lane; KP23.20)

As for the right lane, driven speed on the left lane was influenced by the distance to the lane deviation; again the closer is the lane deviation, the slower is the traffic.

The second period is again characterized by more homogeneous (5 minutes mean) speeds. Higher speeds are recorded on the left (fast) lane as higher variance are recorded speed behavior is less homogenous. However based on the data collected driven speed remains close to the temporary speed limit.

6h time period – Average, P85 & variance of 5 minutes mean speeds

		Layout 1	Layout 2		Layout 1	Layout 2
00h-->06h	#datasets	318	142			
	Avg	76,5	71,6	>70km/h	72,6%	42,3%
	Variance	143,5	176,8	>75km/h	54,4%	28,9%
	P85	87,2	80,6			
06h-->12h	#datasets	774	367			
	Avg	75,4	67,7	>70km/h	84,8%	22,9%
	Variance	38,8	26,8	>75km/h	49,9%	6,3%
	P85	81,1	71,5			
12h-->18h	#datasets	837	469			
	Avg	75,9	68,1	>70km/h	83,8%	33,9%
	Variance	33,8	25,0	>75km/h	53,4%	6,4%
	P85	82,2	72,8			
18h-->00h	#datasets	693	360			
	Avg	80,1	71,6	>70km/h	92,6%	60,8%
	Variance	62,6	41,2	>75km/h	78,9%	26,4%
	P85	87,1	77,3			

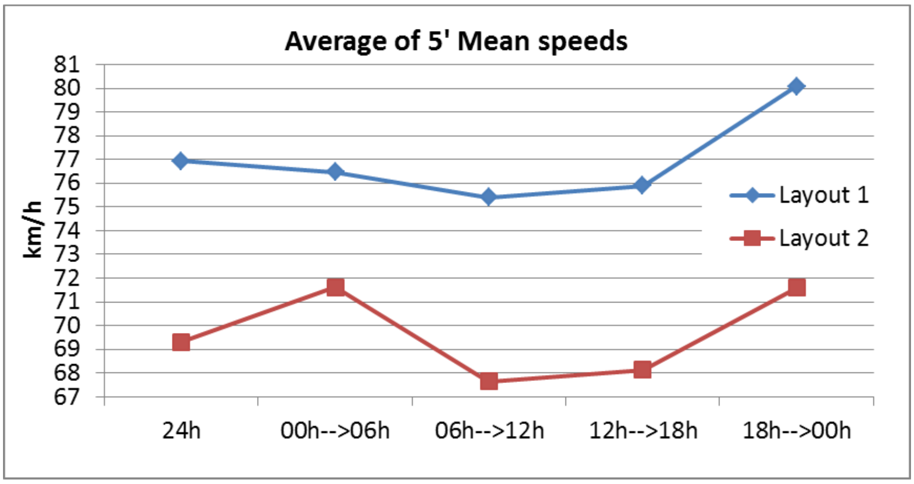


Figure 79: Average, P85 & variance of 5 min. mean speeds (6h time periods; left lane; KP23.20)

Table and graph on **Figure 79** show to what extend higher speeds were recorded in night time (from 18h till 06h). The percentage of over speeding vehicles is also more important during that period.

3.5.3.4 Conclusion and perspectives

The A21/E34 showcase carried out by BRRC simply consisted in a speed monitoring campaign. As explained in the chapter 3.4.3.1 various devices were installed by the road manager along the advanced warning and transition areas (VMS, temporary gantry, speed display, rumble strips) to mitigate over speeding risk; however no variation occurred in the deployment of these devices during the monitoring campaign.

Speed was monitored across two consecutive periods; each characterized by a particular road work layout; i.e. stage 1 by a crossing of the central reserve – speed recorded 250m upstream of the deviation; and stage 2 by a shift of the trafficked lane to the right – speed recorded 50m upstream of the lane shift.

One should also note that the speed was limited to 70km/h along the lane deviation and in the crossing of the central reserve (for which the design has been adapted - longer transition, softer deviation angle- to provide safe traffic conditions).

The different results presented along the two last sub-chapters lead to the following main conclusions:

- Speed data recorded 250m upstream of the crossing of the central reserve remain close to the speed limit (higher speeds being recorded on the left lane) for both layouts/periods;
- for both layouts/periods the speed variance at this location remains quite low; showing a relatively homogeneous speed behavior on both lanes;
- The analysis based on the 6 hours' time periods confirmed that higher speeds were recorded in night time; with 3 to 5 km/h (5 minutes Mean speed average) difference between night-time and day-time periods depending on the lane considered;
- It appears clearly that driven speed seems to be very much influenced by the distance to the lane deviation; the closer is the lane deviation, the slower is the traffic; and this independently of the type of road work layout.

The cooperation with the Road authority has been very positive. However, the implementation of this showcase has been a time consuming task that needed several contacts with various actors. An automatic speed camera was supposed to be deployed during the monitoring period by the Police but has been unfortunately canceled.

Nevertheless this showcase already delivers interesting learnings from which the following perspectives can be drafted.

<u>Perspectives for future work</u>

- Program a new speed monitoring campaign to confirm the global trends observed; i.e. speed behavior vs time of the day, speed vs traffic volume, and to confirm the speed behavior in presence of a longer/70kph crossing of the central reserve in comparison to a short/50kph one;
- Consider additional external parameters in the process to better understand the traffic and speed behavior (e.g. weather, activity on the work zone, queuing start and end) and tracking the traffic condition to fine tune the data filtering (to exclude strongly impacted traffic flow);
- Perform an evaluation (spatial & temporal effect) of the effectiveness of an automatic speed camera in addition to the speed management methods already used (transversal rumble strips, speed display, temporary signing gantry, VMS trailer);
- Coordinate the speed control and speed monitoring from the early planning of the road works project and combine several speed monitoring devices;
- Secure the installation and operational maintenance of the speed & traffic monitoring devices and of the data retrieval.

3.5.4 *Experiment in the Driving simulator*

3.5.4.1 Data processing and results

The analysis of speed data was used as an indicator the driver's perceived risk of travelling through a specific area of the work zone. For the comparative analysis between the configurations, the mean speeds, standard deviations and speed variances were calculated.

According to the results of WP2, the change in speed variance (in percentage), from upstream to work location can be used as an indicator of the improvement (or of the worsening) of safety for the different work zone configurations. In fact the study conducted by Migletz et al (1993) showed that the safest traffic flow occurs when all vehicles are travelling at approximately the same speed, which means that the range of speeds is within a relatively narrow band and the speed variance is small. As speed variance increases, crashes tend to increase. Furthermore the results show that the safest work zones are those with the smallest increase in the upstream-to-work-zone speed variance.

However, Migletz also states that consideration must be given to the question whether or not a speed limit reduction is adequate enough to provide for the safety of construction personnel who must work in exposed positions along the travelled way

The mean speeds and standard deviations were utilized in statistical test (t-student test) to determine if the difference between the speeds for the different configurations was statistically significant. The test was carried out with at a 95% level of significance (α=0.05).

Table 19: Summary of the results from the simulator study (analyse in the next chapters)

Configuration		Measurement site											
		A	B	C	D	E	F	G	H	I	J	K	L
0	Mean speed (km/h)	122.1	116.0	110.5	101.2	70.9	81.8	93.3	79.9	128.9	54.5	51.1	54.5
	Std. Dev (km/h)	11.7	12.6	13.4	15.3	14.7	7.3	14.7	12.9	7.7	9.8	8.7	9.7
0_VMS	Mean speed (km/h)	118.1	112.0	108.1	101.6	72.1	82.6	94.4	81.3	128.7	52.9	49.4	51.9
	Std. Dev (km/h)	12.6	11.2	11.5	12.4	11.3	6.7	15.3	14.8	9.5	10.9	11.1	9.5
1	Mean speed (km/h)	121.2	117.2	114.5	105.1	73.8	85.5	97.5	88.3	127.8	63.9	63.0	68.7
	Std. Dev (km/h)	11.1	13.2	14.2	15.8	12.3	7.0	13.2	13.5	8.6	8.8	9.4	10.3
2	Mean speed (km/h)	125.0	118.1	111.4	101.3	74.0	87.0	96.0	82.1	130.3	54.2	50.2	57.2
	Std. Dev (km/h)	12.1	13.0	14.0	14.3	13.7	9.3	16.5	16.6	10.4	11.5	14.4	11.0
3	Mean speed (km/h)	123.3	117.5	113.6	104.2	76.3	89.1	99.3	89.9	128.6	66.7	65.9	71.3
	Std. Dev (km/h)	11.8	13.9	12.9	12.9	11.2	9.6	15.8	14.3	10.2	11.9	11.5	13.0

Configuration "0"

In the configuration "0" the average speed recorded within a 1.5 km long segment (segment 1, **Figure 80**) upstream of the work zone is about 127 km/h with a generalized speed limit on motorways of 130 km/h. Then the drivers approach the warning area with a mean speed of 122 km/h in correspondence of the "road work" sign (site A) and start reducing progressively the speed with a mean deceleration of 0.34 m/s2 up to the location where the closure of the right lane occurs.

The mean speeds in correspondence of the "110 km/h speed limit" sign (site B) and in proximity of the "90 km/h speed limit" sign (site C) are respectively 116 km/h and 110 km/h and in site D ("60 km/h speed limit" sign) the drivers adopt a mean speed higher than 100 km/h.

Along the transition area the speed decreases significantly at a higher deceleration rate equal to about 0.82 m/s2 but at the "40 km/h speed" limit (site E) the mean speed is still about 71 km/h.

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The increase in speed variance (in percentage) from the section upstream (site I) to the section of the “carriageway closure” sign (site J) was about 64 %.

According to the described speed profile, the actual speeds are much higher than the prescribed speed limits (**Figure 80**).

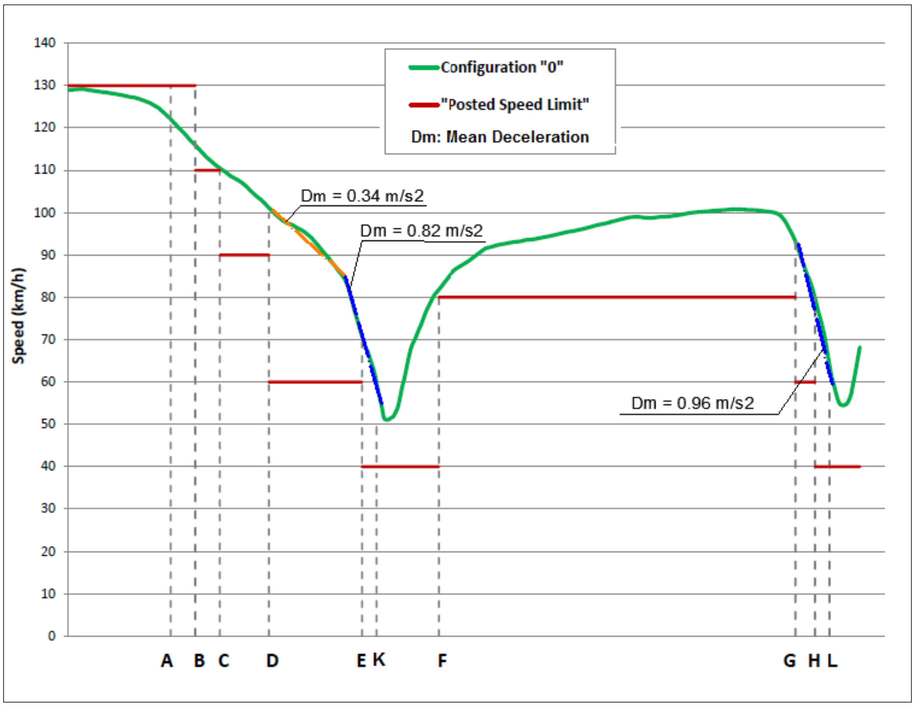

Figure 80: Mean speed profile of the configuration “0”

Even in the 40 m wide “entrance by-pass” (segment 3) where the flow is diverted to the opposite carriageway, the mean speed is about 50 km/h, still higher than the imposed speed limit of 40 km/h.

In the activity area the mean speed is always higher than the prescribed limit: after the end of the “entrance by-pass”, the users start accelerating, travelling with a speed of 82 km/h in correspondence of the “80 km/h speed limit” sign, and reach a maximum speed value higher than 100 km/h. At a distance of about 230 m (similar to the driving behaviour approaching the entrance by-pass) the drivers perceive the presence of the “exit by-pass” and start reducing their speeds with a mean deceleration of about 0.96 m/s^2. The mean speed in the “exit by-pass” is 52.6 km/h.

Based on these results it is possible to conclude that the speeds within each work zone area are always higher than those prescribed by the temporary speed limits. The mean speed decreases significantly only at the beginning of the transition area when the drivers recognize the presence of a physical constraint (the entrance by-pass) perceiving it as a hazard.

The driving behaviour is very similar in the entrance and in the exit by-passes although in the exit by-pass the average speed held by the drivers is 5-10 km/h higher than in the entrance one, likely due to the fact that they already experienced the required driving manoeuvre and that there is no incoming traffic at the end of the manoeuvre.

Comparison of the driving behaviour in configuration "0" and in configuration "0_VMS"

As described earlier the configuration "0_VMS" differs from the configuration "0" only for the installation of the Variable Message Sign (VMS) in place of the "road work" sign. This configuration was implemented in order to investigate the effectiveness of this countermeasure on speed reductions. For this reason the comparison between these configurations was conducted focusing on the speeds recorded in proximity of the site A (from site I to site B), without investigating the other areas of the work zone. In **Figure 81** the mean speed profiles recorded within the warning area in the configuration "0" and "0_VMS" are shown.

The mean speed recorded in correspondence of the upstream section (site I) located 500 m before the site A is about 129 km/h for both configurations. This is likely due to the fact that drivers don't yet perceive the presence of the work zone at this distance.

In site A the mean speed measured in correspondence of the VMS (118 km/h) is about 4 km/h lower than that recorded at the "work zone" static sign (122 km/h). This difference is maintained in the following section (site B) where the speed in the configuration "0_VMS" is 112 km/h. Afterwards, the benefit of the VMS decreases and disappears at site D.

For this reason the evaluation of changes in speed variances from upstream to work location has not been carried out in this configuration.

Despite a decrease in mean speed has been recorded in this two sections due to the presence of the VMS, this difference was not statistically significant.

The use of a VMS equipped with flashing lights might improve the perception of the device and induce the drivers to slow down also from greater distances.

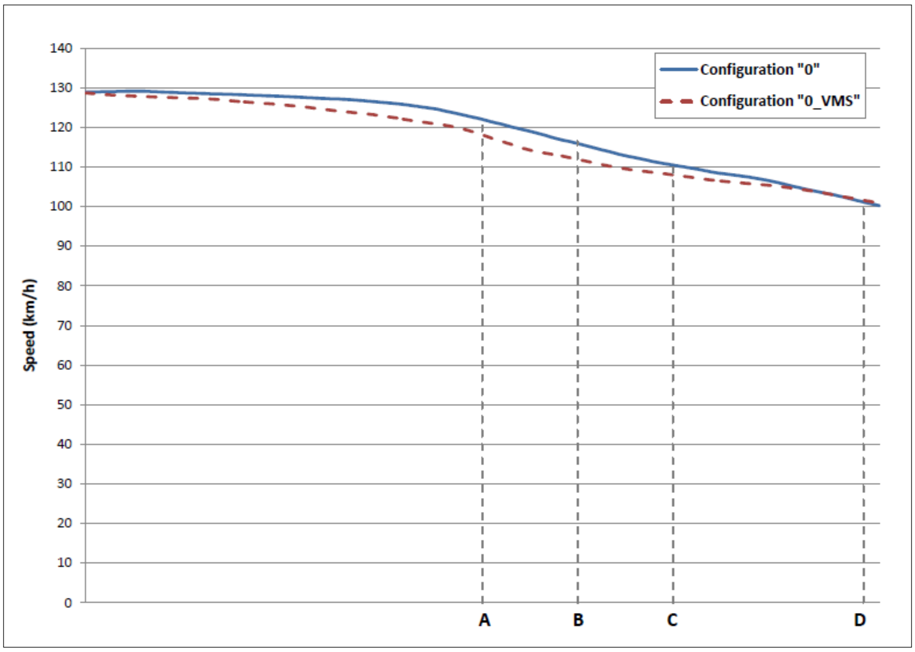

Figure 81: Comparison between speed profiles (configuration "0_VMS" – configuration "0")

Comparison of the driving behaviour in configuration “0” and in configuration “1”

In order to verify the effect of the different sequence of speed limits in the advance warning area and in the transition area adopted in the configuration “1” (110-80-60 km/h, instead of the sequence 110-90-60-40 km/h) the mean speeds and the change of speed variances from the section upstream (site I) to the section of the “carriageway closure” sign (site J) were compared.

The recorded speeds in configuration “1” are globally represented by the mean speed profile shown in **Figure 82**.

A greater compliance with speed limits (which are increased compared to those of the configuration “0”) occurs even if a general speeding behaviour is still present.

A smoother variation of the actuated deceleration can be identified approaching the transition area: instead of actuating the deceleration in two distinct phases, as in configuration “0”, the deceleration gradually increases from 0.38 m/s2 to 0.52 m/s2.

The comparison between the mean speeds profiles of configuration “0” and configuration “1” are shown in **Figure 83**.

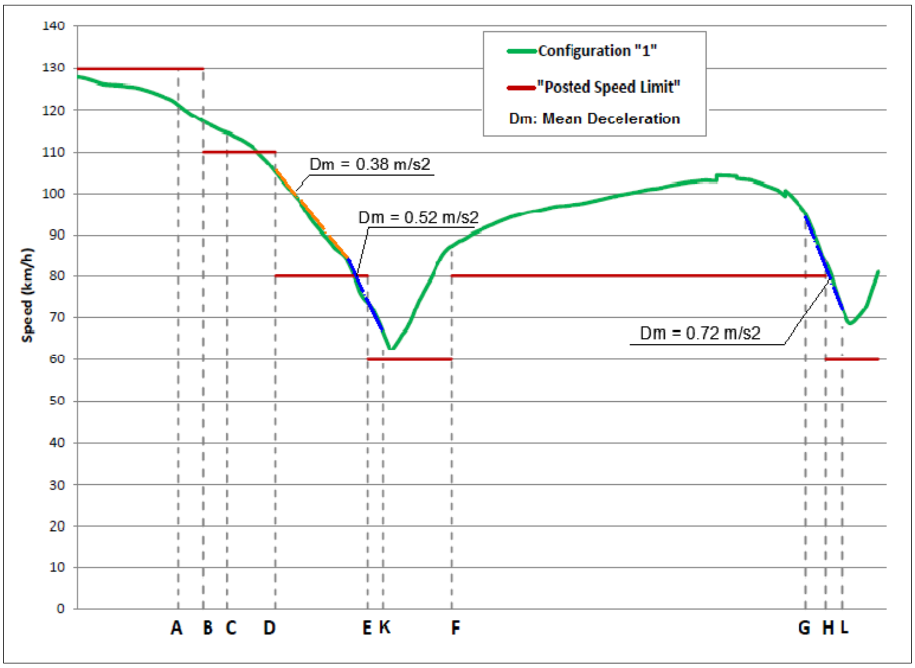

Figure 82: Mean speed profile of the configuration “1”

Within the advance warning area (see definition of the different areas on **Figure 51**), the mean speeds on the configuration “1” are always higher than those of the configuration “0”, while within the transition area the speeds are approximately the same.

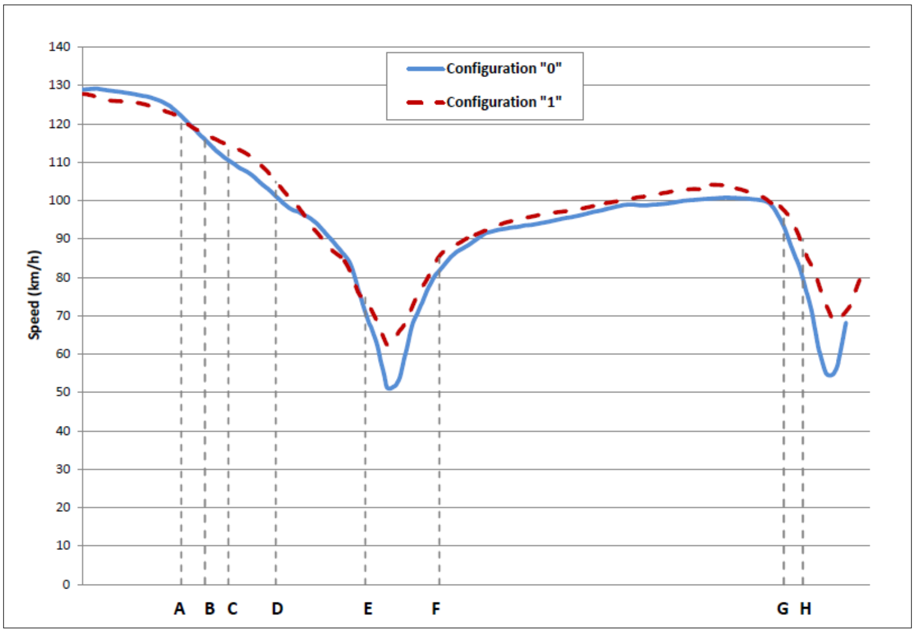

Figure 83: Comparison between mean speeds profiles (configuration “0” – configuration “1”)

However the statistical significance of the recorded speed differences in correspondence of the sites B, C and D is not verified.

The analysis of the change in speed variances from a section upstream (site I) to the section of the “carriageway closure” sign (site J) leads to some interesting results: in the configuration “1” a smaller increase in the upstream-to-work-zone speed variance (+5.2%) has been recorded, compared to that measured in the configuration “0” (+64.5%).

Based on the theory that the safest work zones are those with the smallest increase in the upstream-to-work-zone speed variance, the sequence of speed limits implemented in the configuration “1” seems to provide safer conditions for drivers even if no modification occurs in their speeding behaviour.

However when considering the safety of road workers on foot, Migletz et al.[9] points out that consideration also must be given to the question whether or not a speed limit reduction is adequate enough.

In order to verify the effect of the increase in the opening median’s width adopted in configuration “1” (80 m in place of 40 m), the minimum speed values adopted on this configuration were compared with those adopted on configuration “0”.

The minimum values of the speeds held by the drivers within the by-pass were recorded approximately in the middle of the opening for both configurations.

The comparison shows that the speeds increase as the median opening increases. In correspondence of the entrance by-pass the mean speed increases from 49.8 km/h of the configuration “0” to 62.1 km/h of the configuration “1”, while in correspondence of the exit by-pass the users speed up from 52.6 km/h to 68.1 km/h.

The differences of the speeds within the by-passes are statistically significant according to the t-student test.

[9] Migletz, J. , Graham, J.L., Harwood, D. W., “Procedure for Determining Work Zone Speed Limits,” National Cooperative Highway Research Program, Project 3-41, Transportation Research Board, Washington, D.C., 1993, pp. 214-218

Furthermore, the mean deceleration recorded between the site E (“40 km/h speed limit” sign) and the entrance by-pass is much lower when the drivers approach the 80 m opening width (-0.52 m/s^2) if compared to that recorded approaching the 40 m by-pass (-0.82 m/s^2).

According to this result it can be concluded that a larger opening width allows the users to complete the manoeuvre safely even at higher speeds, avoiding sudden decelerations or abrupt manoeuvres.

Comparison of the driving behaviour in configuration “0” and in configuration “2”

In order to investigate the effect of the increased lane width in the configuration “2” (5 m instead of 3.75 m of the configuration “0”) the mean speeds along the transition and the activity areas and the change of speed variances from site I to site J were compared.

The mean speed profiles (**Figure 84**) show a general increase of speeds when drivers travel along the 5 meter lane within the advance warning area, while within the transition area the speeds are approximately the same.

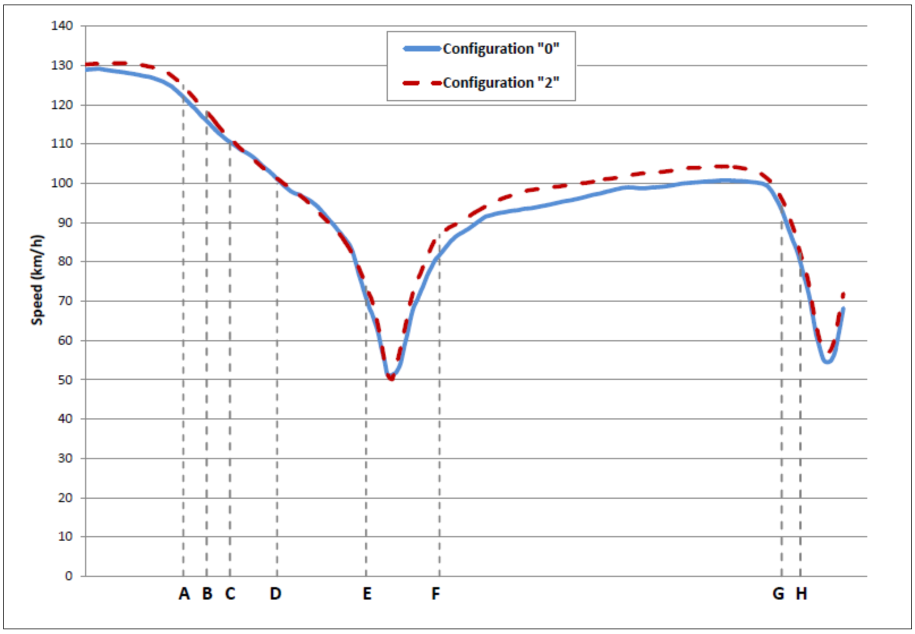

Figure 84: Comparison between mean speeds profiles (configuration “0” – configuration “2”)

However the increase of speeds is particularly evident when the users drive in the opposite carriageway: the average speed recorded within a 1.5 km long segment (segment 2, Figure 88) in the activity area (100.2 km/h) is higher than that recorded in the same segment when the lane is 3.75 wide (96.6 km/h).

The analysis of the change in speed variances shows a smaller increase in the upstream-to-work-zone speed variance (+23.6%) for the configuration “2” if compared to that measured in the configuration “0” (+64.5%).

However the increase of speed variance is greater than the one recorded for the configuration “1” (+5.2%). According to this result a wider lane width does not seem to provide safer conditions if compared to the configuration “1”.

Furthermore the lane width seems to be a factor that influences the speeds within the by-pass independently from its width: in fact in the configuration "2" the mean speed within the entrance by-pass (51.7 km/h) is slightly higher than the one recorded in the configuration "0" (49.8 km/h).

This result is likely due to the fact that the lane width influences the trajectory of the travelling vehicles, leading, in case of wider lanes, to greater freedom to manoeuvre for the users approaching the by-pass.

Comparison of the driving behaviour in configuration “0” and in configuration “3”

The experimentation on the configuration “3” was developed in order to evaluate, with respect to configuration “0”, the effects of the contemporary implementation of the different sequence of speed limits (together with the 80 m opening width) and of the wider lane (5 m).

The speeds recorded in the configuration “3” are, as expected, higher than those recorded in all the previous configurations.

In particular the mean speed within the activity area (segment 2) is about 102.6 km/h, 6 km/h higher than that of the configuration “0” (**Figure 85**).

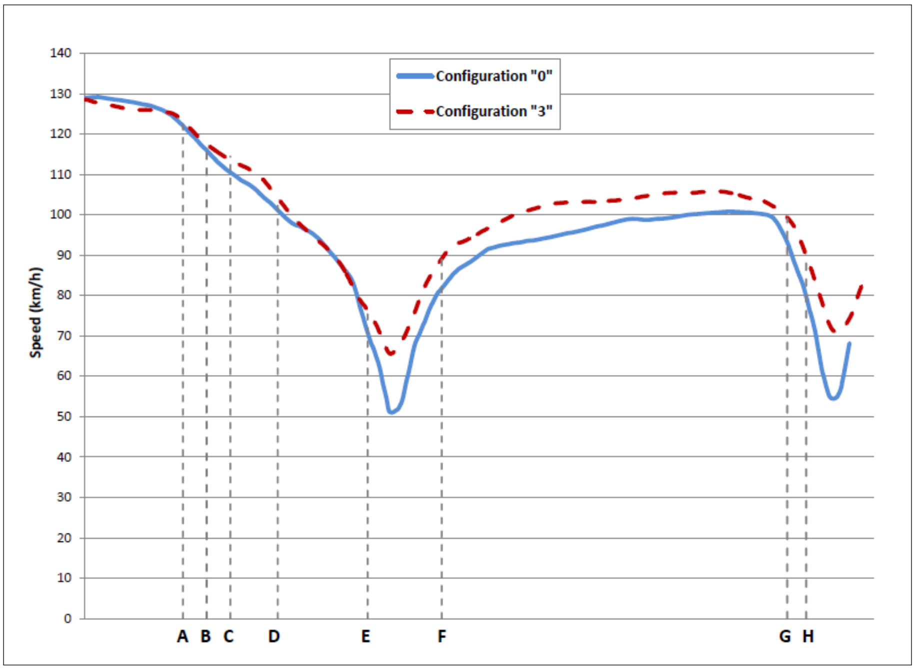

Figure 85: Comparison between mean speeds profiles (configuration “0” – configuration “3”)

The analysis of the change in speed variances shows a smaller increase in the upstream-to-work-zone speed variance (+36.0%) for the configuration “3” if compared to that measured in the configuration “0” (+64.5%).

However the increase of speed variance is much higher than those recorded within the configuration “1” (5.2 %). Based on this result it is possible to conclude that also the configuration “3” does not seem to provide safer conditions compared to the configuration “1”.

The wider lane width seems to lead to higher travelling speeds. This is confirmed from the comparison between the configuration of "3" and the configuration "1" in which, despite the same opening width (80 m), the mean speed is higher when the users travel on a 5 meter lane (**Figure 86**).

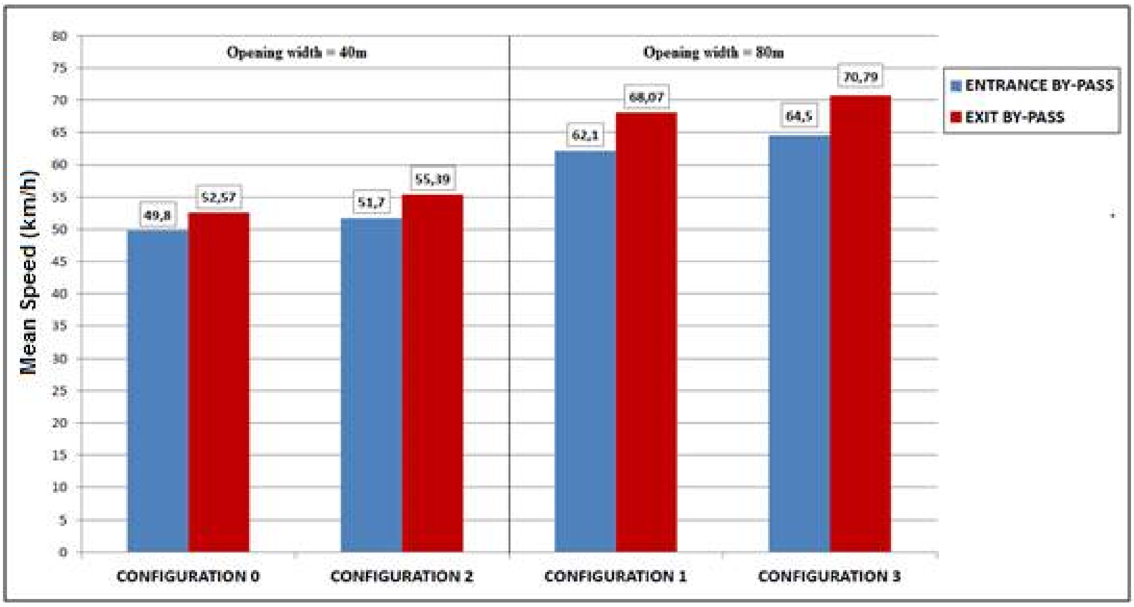

Figure 86: Mean speeds within the by-pass for the different configurations

3.5.4.2 Conclusions

The specific purpose of this research was to determine the effectiveness of five different configurations of a work zone crossover on drivers' behaviour.

The main findings of the analysis can be summarized as follows:

- the drivers travel within the work areas at higher speeds than those indicated by the temporary speed limit signs for all configurations;
- the mean speed decreases significantly only within the entrance and the exit by-pass even if the mean speed is still higher than the imposed speed limit;
- in the configuration "1" a smaller increase in speed variance (+5.2%) from upstream to work location was recorded as compared to the one measured in the configuration "0" (+64.5%);
- the increase in the opening median's width from 40 m to 80 results in an increase of the mean speeds between 12 and 16 km/h;
- the mean deceleration recorded between the site E ("40 km/h speed limit" sign) and the entrance by-pass is always much lower when the drivers approach the 80 m opening width if compared to the one recorded in approach to the 40 m by-pass;
- a wider lane width (5 m in place of 3.75 m) for the transition area does not seem to provide safer conditions if compared to the configuration "1". The lane width seems to be a factor that influences the speeds within the by-pass independently from its width. The comparison between the configurations with the same opening width shows a slightly higher mean speed for the users travelling on the 5 meter lane;
- the contemporary implementation of a wider lane and of a larger opening width (configuration "3) does not seem to add further improvements compared to the other configurations. Furthermore in this configuration the highest mean speeds were

recorded along all the work zone areas and in particular within the activity area where the mean speed was about 20 km/h greater than the temporary limit;

- the installation of a Variable Message Sign (VMS) seems to provide some effects on reducing speeds: the mean speed measured in correspondence of the VMS is about 4 km/h lower than that recorded at the “work zone” static sign. The difference is maintained within the first part of the advance warning area (up to site D). However the VMS loses its effectiveness in the following sections.

Among all the configurations analyzed in this study the configuration “1” seems to lead to the safest conditions for drivers. The sequence of speed limits “110-80-60 km/h” implemented within the advance and the transition area determined the smallest increase in speed variance from upstream to work location, showing a significant homogeneity of the speeds adopted by the drivers.

However, consideration must also be given to the fact that the higher the impact speed, the more serious the consequences in terms of injury and material damage (Elvik, 2009). For work zones, Migletz points out that consideration also must be given to the question whether or not a speed limit reduction is adequate enough to provide for the safety of road workers on foot.

Furthermore a smoother variation of the actuated deceleration has been identified approaching the transition area: instead of actuating the deceleration in two distinct phases, as in configuration “0”, the deceleration gradually increases from 0.38 m/s^2 to 0.52 m/s^2.

Finally the 80 m opening width seems to allow the users to complete the manoeuvre safely even at higher speeds, avoiding sudden decelerations or abrupt manoeuvres.

3.6 Conclusion from the showcases

The ASAP showcases have been a unique opportunity to test and demonstrate interesting speed management measures identified during the first half of the project. Consequent resources have been used and positive effects have been observed with some of the measures. Though a practical approach the showcases contribute to the consolidation of knowledge and experience about speed behavior, speed management and speed monitoring at road works sites. Moreover they emphasize important deployment issues.

Speed monitoring campaigns carried out on site in the Czech Republic and in Belgium and experiments in the Italian driving simulator revealed significant differences in term of speed behavior across the different showcases (see **Table 20**). This may be (at least partially) explained by the number of warning equipment deployed along the advance warning and transition areas on the Belgian sites and by the fact that over speeding is now regularly enforced by automatic cameras in Belgium.

Analysis based on 6 hours’ time periods confirmed that higher speeds are typically recorded in night time. The period of the day is an important factor when looking at speed behavior and speed amplitudes observed between different periods of the day are usually higher that between periods with and without activation of a specific speed management measure.

From the studies it appears that the use of a speed camera sign in the advance warning area clearly impacts driven speeds in the Czech Republic. Mean speeds and standard deviation were also positively impacted by the (speed activated) VMS trailer installed in the Czech work zone as well as by the Police car presence. However, the VMS LED trailer installed in

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the advance warning area didn't seem to significantly impact the driven speed around the transition area (i.e. 1300m downstream).

The experiment in the driving simulator demonstrated that the installation of a Variable Message Sign (VMS) may provide some effects on reducing speeds (the mean speed measured in correspondence of the VMS was about 4 km/h lower than that recorded at the "work zone" static sign); the difference being maintained within the first part of the advance warning area. However the VMS loses its effectiveness in the following sections.

The presence of the Automatic Speed Camera seems to have an impact on the mean speed and on the proportion of drivers exceeding the temporary speed limit. This is particularly visible for daytime traffic. However it is likely that the speed camera has a local impact that decreases when progressing along the work zone. To what extend still needs to be determined.

Alternative geometries of the central reserve crossing and speed limit schemes have been tested in controlled conditions (i.e in a driving simulator). This part of the study interestingly indicated that even if a wider opening of the central reserve combined with a slightly higher speed limit result in an increase of the mean speed (between 12 km/h and 16 km/h), both the speed variance from upstream to work location and mean deceleration around the by-pass entrance are much lower than in the reference situation. Following the literature these elements are supposed to lead to lower accident rates.

Important conclusions may also be drafted for what concerns the deployment of the speed management measures and speed monitoring devices. Generally speaking, in such monitoring a communication plan is needed at the early stage of the road work planning to identify and commit the various actors. An operational plan is also necessary to schedule the deployment of equipment, to efficiently operate the various devices and organize the data collection.

Deploying and maintaining speed monitoring equipment and speed management measures remains a time consuming task. One important element with such speed monitoring campaigns is linked to the location of the speed detectors. As far as possible their location should be fixed by monitoring needs only; i.e. located where it is interesting to measure speed to be able to evaluate the spatial effectiveness of the speed management measure, and not where e.g. a support pole or power supply is present. This is an important deployment issue that must be considered for all further implementation activity.

Implementation issues are further discussed in the next chapter.

The ASAP showcases addressed some important issues but also emphasized unsolved questions that offer interesting perspectives for further studies; as listed hereafter:

- Reproduce speed monitoring campaigns to confirm the global trends observed; i.e. speed behavior vs time of the day, speed vs traffic volume, speed behavior in presence of a longer/70kph crossing of the central reserve in comparison to a short/50kph one, higher speed variance at locations close to the transition area, indicators for speed congestion and focus on more homogeneous monitoring periods (duration, traffic characteristics, weather conditions RW activity & configuration).
- Include additional external parameters in the process to better understand the traffic and speed behavior (e.g. activity on the work zone, queuing start and end, weather).
- Confirm the effect of the installation of a speed camera sign and particularly investigate its spatial and temporal effectiveness, combined (and not) with police patrol presence;
- Further study the impact of (repeated) speed activated signs and VMS; ideally in combination with license plate recognition and/or Police presence/controls;

- Repeat speed monitoring campaigns with a VMS trailer used in the advance warning area and dedicated to danger driver warnings and potentially about speed control actions;
- Continue the evaluation of the effectiveness of the automatic speed camera; i.e. evaluate the spatial & temporal effect by more consistent monitoring periods and successive monitoring locations.

4 PRACTICAL CONSIDERATIONS RELATED TO THE IMPLEMENTATION OF THE SELECTED MEASURES

Based on the experience gained during the showcase this chapter discusses some main implementation issues related to the speed management methods tested/studied during the showcases. Doing so it aims to contribute to the recommendations being developed in WP5 about effective strategy and measures to manage speed through road works zones.

4.1 Speed management strategy

Experience has shown that the level of compliance with speed limits is very much dependent on the credibility of the speed limits (i.e. in line with the drivers' expectations). When the speed limits are credible a positive effect is expected on average driving speeds and on homogeneity of the traffic flow. US literature suggests that speed compliance in work zones is generally much higher where the speed limit reduction is rather small (< 20km/h). Homogeneity of speed is also important because literature indicates that the safest traffic flow occurs when all vehicles are travelling at approximately the same speed.

However most of the European countries typically use multiple levels of 20 km/h (or higher) speed reductions. The ASAP showcases followed this latter strategy, with some variation as shown on **Table 20** that synthesizes some of the showcase results.

Before trying to conclude from this table, one should remind that the speed wasn't necessarily monitored at the same location for all the sites (this was a showcase, not a pilot testing) and, except for the test in the simulator, wasn't monitored at each step of speed limit reduction. Moreover the testing sites were not all signed or equipped in the same way. Nevertheless the table interestingly tends to:

- confirm that the larger is the speed limit reduction the larger is the gap between speed limit and driven speeds (c.f. the results from the driving simulator);
- show that smaller speed limit reductions do not necessarily leads to less speed compliance and even seems to contribute to homogenizing speed variances (cf. Belgian showcases);
- indicate that the reinforcement of the road work signing by use of (a combination of) dynamic signs in the advanced warning area, speed camera sign or speed display close to the transition area is quite beneficial to warn drivers and reduce noncompliance to speed limits (cf. monitoring campaign along the A21/E34 motorway)..

These results demonstrate again that identifying the appropriate speed limit remains a difficult task and that small speed limit reductions do not necessarily means lower safety levels, if the design of the transition area is adapted to comply higher speed level (as was the case on the E34/A21 motorway and in the driving simulator).

Temporary speed limits are decided considering the national rules, standards, guidelines and common practices. However when making this decision a certain degree of freedom sometimes remains.

Table 20: Speed limit regimes tested in the showcases & driven speeds

Speed limit regime	**Layout type**	**Signing / Speed management**	**Average Speed**	**P85 speed**	**Variance**	**Speed monitoring location / Temporary Speed limit**
D1 motorway, CZ *						
130→100→80	Lane deviation	Static signs	Right lane: 108 km/h Left lane: 127 km/h	/	Right lane: 65 km/h Left lane: 79 km/h	300m upstream the lane deviation / 80 km/h
130→100→80→60→80	Crossing of the central reserve		Right lane: 108 km/h Left lane: 123 km/h	/	Right lane: 61 km/h Left lane: 85 km/h	500m upstream the lane deviation / 100 km/h
E42/A15 motorway, Belgium *						
120→90→70→50→70	Lane deviation & Crossing of the central reserve	Static signs, fixed & mobile VMS in the advanced warning area, Speed camera sign	Right lane: 64 km/h Left lane: 73 km/h	Right lane: 73 km/h Left lane: 79 km/h	Right lane: 89 km/h Left lane: 34 km/h	200m upstream the central reserve crossing (close to a motorway access) / 70 km/h

<table>
<tr><td colspan="7">E34/A21 motorway, Belgium *</td></tr>
<tr><td>120→90→70</td><td>Crossing of the central reserve</td><td rowspan="2">Static signs, mobile VMS in the advanced warning area, speed display, temporary gantry, etc.</td><td>Right lane: 70 km/h
Left lane: 77 km/h</td><td>Right lane: 74 km/h
Left lane: 84 km/h</td><td>Right lane: 17 km/h
Left lane: 60 km/h</td><td>250m upstream the central reserve crossing / 70 km/h</td></tr>
<tr><td>120→90→70</td><td>Lane deviation</td><td>Right lane: 65 km/h
Left lane: 69 km/h</td><td>Right lane: 69 km/h
Left lane: 75 km/h</td><td>Right lane: 15 km/h
Left lane: 49 km/h</td><td>50m upstream the central reserve crossing / 70 km/h</td></tr>
<tr><td colspan="7">Driving simulator, Italy **</td></tr>
<tr><td>130→110→90→60→40 →80</td><td>Lane deviation</td><td rowspan="4">Static signs</td><td>101 km/h</td><td>/</td><td>/</td><td>200m upstream the lane deviation / 60 km/h</td></tr>
<tr><td>130→110→80→60→80</td><td>Lane deviation</td><td>105 km/h</td><td>/</td><td>/</td><td>200m upstream the lane deviation / 80 km/h</td></tr>
<tr><td>130→110→90→60→40 →80</td><td>Crossing of the central reserve</td><td>71 km/h</td><td>/</td><td>/</td><td>130m upstream the central reserve crossing / 40 km/h</td></tr>
<tr><td>130→110→80→60→80</td><td>Crossing of the central reserve</td><td>74 km/h</td><td>/</td><td>/</td><td>130m upstream the central reserve crossing / 60 km/h</td></tr>
</table>

(*: calculated from 5 minutes aggregated & filtered data; **: average of speed driven within the simulator)

Indeed from a theoretical point of view it is to some extent possible to customize the speed limit scheme.

As mentioned in the ASAP Deliverable 2.1 “State of the Art on Speed Management Methods” different criteria are used across Europe to assign work zone speed limit, the two main (i.e. used in the majority of the countries) being the original posted speed and the road type. Other criteria are common but are not necessarily exploited in all the EU countries; they are candidate criteria a road manager may use to derogate from classical speed limit schemes and they also represent a chance for harmonization of practices:

- The proximity and protection of workers (the two criteria most commonly identified by stakeholders as most safety critical were “Original posted speed” and “Proximity of workers to traffic”): working with a larger lateral safety distance, with additional buffer zones or installing high-performance safety barriers may give opportunities to avoid one step of speed limit reduction;
- The impact on traffic: in some circumstances the impact on traffic may be reduced by adapting the phasing of works (that may impact space necessary for work and circulation of the work vehicles) and/or the cross-section (i.e. lane width coupled with the use of safety barriers);
- The design of the crossover: softer lane deviation (smaller deviation angle) and slightly larger lane width.

The A21/E34 Belgian showcase is a good example of a customization of the speed limit scheme (**Figure 87**). As shown in chapter 3.4.3.1, the speed was there limited to 70km/h along the lane deviation and in the central reserve crossing. Such a practice is not much common on Belgian motorways (in such situations speed is usually limited to 50km/h). This speed limit was considered safe because the design of the transition area has been adapted. In particular the opening of the central reserve has been enlarged to around 150m thanks to the removal of a lighting pole.

Figure 87: 2014 Road works along the A21/E34 Belgian motorway: longer transition, softer deviation angle in the crossover

4.2 Implementation issues of the speed management methods tested/studied during the showcases

This chapter reminds the speed management measures (and their implementation conditions) showcased during the ASAP project, or more simply that were present on the monitored road work sites. Based on the experience gained during the showcases it also introduces some implementation issues (Where? What benefit? What challenges? What type of costs is associated?) that will be further addressed in the final ASAP deliverable.

1. Trailer carrying a Variable Message Sign (advance warning area)

Characteristics (Message/Sign showed):

A VMS has been tested in the driving simulator and its impact quantified compared to a reference situation (fixed signs only).

A road worker danger sign was displayed together with the message “Riduci la velocità” (“Reduce the speed” in Italian).

The VMS trailer was installed on the right shoulder in place of the standard “road work” sign.

Road work main characteristics:

Crossover in which the traffic flow is diverted to the opposite carriageway in a 1+1 lane configuration. The speed is progressively reduced from 130 to 60 km/h and to 40 km/h in the by-pass. The signs are consistent with the instructions of the Italian technical rules for temporary signs.

Deployment area (during WP4):

The VMS was deployed in the **advance warning area** – 600 m upstream the merge of right and left lane; 1000 m upstream the crossing of the central reserve.

Impact (measured) in term of speed behavior:

Compared to the use of standard “work zone” static sign:

- 4 km/h lower at the VMS location (118 km/h compared to 122 km/h; speed limit 130 km/h);
- 4 km/h lower 120m downstream (112 km/h compared to 116 km/h; speed limit 110 km/h);
- 2 km/h lower 120m downstream (108 km/h compared to 110 km/h; speed limit 90 km/h);
- No more impact at the next measuring point (240m downstream; speed limit 60 km/h).

On-site deployment issues:

See sections 2 and 8 hereafter.

Cost components:

Not relevant (driving simulator).

Questions to be further studied/discussed:

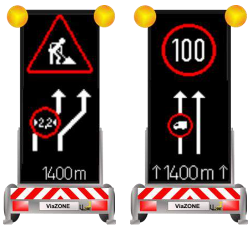
The use of a VMS equipped with flashing lights might improve its perception and induce the drivers to slow down also from greater distances.

The findings with driving simulator generally confirm the results of the previous research. While the deployment of VMS was found effective in some studies, some researchers argued that its effect is temporary or localized. Some studies claimed that radar-activated VMS had only a “novelty effect” which was not sustained over time. Dixon and Wang (2002)[10] reported speed reductions of 6-8 mph immediately adjacent to the speed feedback system; however the effects did not appear to extend to the active work area.

The VMS could be repeated downstream to alert drivers to road/lane closures or to the presence of workers. However the overuse of VMS should be avoided since it could reduce the VMS effectiveness as drivers tend to stop reading them. Furthermore the deployment of the trailer mounted VMS requires an adequate shoulder width. The messages should be essential (limited to 2-part, 3-word text if possible) and provide specific instructions

2. Trailer carrying VMS - LED matrix (advance warning area)

Characteristics (Message/Sign showed):



A LED VMS has been tested along the CZ motorway (towards Prague). Two display schemes were used and their impact compared to a reference situation (fixed signs only) :

1. Road works sign on upper display + temporary lane configuration on the bottom display;
2. Speed sign “100” on upper display + HGV restriction for left lane on the bottom display.

Road work main characteristics:

The traffic was guided into the right traffic lane by a system 2+2 in the direction from Brno to Prague. The traffic flow directions were separated by a temporary crash barrier. Therefore towards Prague right and left lanes were shifted to the right (with a reduced width).

Deployment area (during WP4):

The LED VMS trailer was deployed in the **advance warning area** (towards Prague) – 1300 m upstream the shift of right and left lane.

Impact (measured) in term of speed behavior:

1300 m downstream the LED VMS trailer location, minor changes of mean speeds and standard deviations were observed.

On-site deployment issues:

Power supply was managed from the grid (SOS cabinet).

The deployment of the trailer needed an authorization from the Road Authorities (RA - Ministry of Transport, Highway directorate, Ministry of Interior) that was delivered after the deployment scheme has been approved. The RA required the equipment being installed outside of the carriageway and ideally behind the guardrail).

The integration of a license plate recognition system to the trailer is an option but was not yet operational for the summer showcase.

Cost components:

Such a trailer cost around 25.000€ without methanol fuel cells (5.500 Euro). The integration of the trailer to the complex management system (e-CON controller) costs 2.000€ more. Various installation costs must also be taken into consideration; e.g. plugin to the grid: 800€, Travel and

[10] Dixon, K.K., Wang, C. (2002). Development of Speed Reduction Strategies for Highway Work Zones. Research Report. Georgia Transportation Institute, Georgia Institute of Technology, Atlanta, GA.

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person costs and cost for communication purpose (SIM card).

Renting solutions are also usually possible but was not practices in CZ.

Questions to be further studied/discussed:

Since the trailer has only been installed around 1300m in front of the transition area, and given the impact is known to be mainly local it might be interesting to further investigate how long the influence area of the measure is.

3. Speed camera sign

Characteristics:

The use of a fixed speed camera sign (“Speed camera present”) has been tested along the CZ motorway (towards Brno).

The sign was installed along the carriageway (in the verge). However no camera was installed.

Road work characteristics:

The traffic was guided into the right traffic lane by a system 2+2 in the direction from Brno to Prague. The traffic flow directions were separated by a temporary crash barrier. Therefore towards Brno right and left lanes were shifted to the left side of the central reserve (contraflow with a reduced width).

Deployment area (during WP4):

The Speed camera sign was installed in the **advance warning area** (towards Brno) –1600 m upstream the crossing of the central reserve.

Impact (measured) in term of speed behavior:

The impact of the speed camera sign has been measured 1100 m downstream the sign location. Better speed compliance an lower speed standard deviation were observed when the sign was present on site: -2,5 km/h and -4 km/h for right and left lanes respectively (the higher speed reduction being measured during afternoon period).

On-site deployment issues:

The installation of the sign needed the agreement of both the Ministry of Transport and Police department.

Czech road users are not used to such warning as this sign isn’t usually used along CZ road work sites.

Cost components:

Costs associated with this measure are very low (sign furniture, installation and regular maintenance).

Questions to be further studied/discussed:

This measure is likely to be ineffective if not combined with automated speed enforcement, occasional speed control or police presence. Combination of Sign and Speed control, as well as alternative Sign location should be further investigated.

The effect of this measure on non-motorway road work sites should also be quantified.

4. Design of the central reserve crossing + Speed limit scheme
<u>Characteristics</u> : An alternative design of the central reserve crossing (longer length of the opening: 80 m) combined with a modification of the speed limit scheme (110-80-60 km/h) has been tested in the driving simulator and the impact quantified compared to the reference situation (40m opening and 110-90-60-40 km/h scheme).
<u>Road work main characteristics</u>: Crossover in which the traffic flow is diverted to the opposite carriageway in a 1+1 lane configuration. The speed is progressively reduced (see above). The signs are consistent with the instructions of the Italian technical rules for temporary signs.
<u>Deployment area and road works characteristics</u> (during WP4): This measure (speed limit scheme + crossing design) applies to the **advance warning** (around 850 m upstream the crossing of the central reserve) and **transition areas**.
<u>Impact (measured) in term of speed behavior</u>: A greater compliance with speed limits (which are increased compared to those of the reference situation) occurs even if a general speeding behaviour is still present. A smoother variation of the actuated deceleration can be identified approaching the transition area. The analysis of the change in speed variances from a section upstream to the transition area shows that the alternative design combined with higher speed limit scheme leads to a smaller increase in the upstream-to-work-zone speed variance (+5.2% compared to +64.5% in the reference situation). Therefore the sequence of speed limits implemented in the alternative seems to provide safer conditions for drivers even if no modification occurs in their speeding behaviour. However attention must be paid to the impact of higher speed on road worker safety. The study also indicate that a larger opening width allows the users to complete the manoeuvre safely even at higher speeds, avoiding sudden decelerations or abrupt manoeuvres
<u>On-site deployment issues</u>: Not relevant (driving simulator).
<u>Cost components</u>: A slight modification of the speed limit scheme doesn't lead to additional costs. However a longer opening of the central reserve would cause additional work and need more materials: demolition of the central reserve, equipment removal, longer base layer and pavement. The total cost of this measure would be highly dependent on the initial situation.
<u>Questions to be further studied/discussed</u>: Most of the national guidelines do not provide detailed information about the speed limit to be imposed in correspondence of the crossover. The number of lanes for each direction, the number of the shifted lanes and the opening of the central reserve represent the main factors that can affect the vehicles' trajectories and their speed profiles, The national guidelines should account for these parameters in the selection of the temporary speed limit.

5. Lane width (transition area & contraflow)
<u>Characteristics</u> : An alternative lane width (5m lane width in the area between the right and left lanes merge and

the central reserve crossing and along the contraflow) has been tested in the driving simulator and the impact quantified compared to a reference situation (3,75m lane width).

Road work main characteristics:

Crossover in which the traffic flow is diverted to the opposite carriageway in a 1+1 lane configuration. The speed is progressively reduced from 130 to 60 km/h and to 40 km/h in the by-pass. The signs are consistent with the instructions of the Italian technical rules for temporary signs.

Deployment area and road works characteristics (during WP4):

This measure applies to the **transition area**.

Impact (measured) in term of speed behavior:

The mean speed profiles show a general increase of speeds when drivers travel along the 5 meter lane within the advance warning area, while within the transition area the speeds are approximately the same. However the increase of speeds is particularly evident when the users drive along the contraflow (100 km/h compared to 96.5 km/h).

The analysis of the change in speed variances shows a smaller increase in the upstream-to-work-zone speed variance with a wider lane (+23.6% compared to +64.5%). The lane width seems to be a factor that influences the speeds within the by-pass independently from its width.

On-site deployment issues:

Not relevant (driving simulator).

Cost components:

Provided space is available and do not impact the work zone there is no additional cost associated to this measure.

Questions to be further studied/discussed:

For projects that require lane shifts due to work area limits the following issues should be considered before determining the final lane width to be implemented: Overall roadway width available; Posted speed limit; Traffic volumes through the project limits; Number of lanes diverted; Existing lane and shoulder widths; Roadway geometry (cross slope, vertical and horizontal curves); Truck percentage.

6. Design of the central reserve crossing + Speed limit scheme + Lane width

Characteristics :

An alternative design of the central reserve crossing (longer length of the opening: 80 m) combined with a modification of the speed limit scheme (110-80-60 km/h) and with a larger lane width (5m) in the transition area has been tested in the driving simulator and the impact quantified compared to the reference situation (40m opening, 110-90-60-40 km/h scheme, 3,75m lane width).

Road work main characteristics:

Crossover in which the traffic flow is diverted to the opposite carriageway in a 1+1 lane configuration. The speed is progressively reduced (see above). The signs are consistent with the instructions of the Italian technical rules for temporary signs.

Deployment area and road works characteristics (during WP4):

This measure (speed limit scheme + crossing design) applies to the **advance warning** (around 850 m upstream the crossing of the central reserve) and **transition areas**.

Impact (measured) in term of speed behavior:

The speeds recorded in the combined alternative are, as expected, higher than those recorded in all the previous configurations (cf. point 4 & 5 above). In particular the mean speed within the activity area is about 6 km/h higher than that of the reference configuration.

The analysis of the change in speed variances shows a smaller increase in the upstream-to-work-zone speed variance (+36.0%) as compared to the reference situation (+64.5%). However the increase of speed variance is much higher than those recorded with the higher speed limit and larger central reserve crossing but standard lane width.

On-site deployment issues:

Not relevant (driving simulator).

Cost components:

Refer to measures 4 and 5 above.

Questions to be further studied/discussed:

Refer to measures 4 and 5 above.

7. Speed display

Characteristics:

A portable speed display has been tested along the CZ motorway (towards Prague). The current speed was displayed with the message "Reduce you speed" in case of over speeding. The display was installed in the verge quite close to the traffic due to the lane shift.

Road work main characteristics:

The traffic was guided into the right traffic lane by a system 2+2 in the direction from Brno to Prague. The traffic flow directions were separated by a temporary crash barrier. Therefore towards Prague right and left lanes were shifted to the right (with a reduced width).

Deployment area (during WP4):

The speed display was installed in the **work zone area** (towards Prague) – 800 m downstream the shift of right and left lane.

Impact (measured) in term of speed behavior:

Due to data processing problem, it was not possible to identify the impact of this measure on traffic speed.

On-site deployment issues:

The device was supplied with accumulators that needed to be replaced every 4 days. Such a non-autarkic solution raises maintenance and safety issues.

Being very close to the traffic it has been necessary to build a system to fix the sign to the guardrail, and therefore mitigate wind effect induced by passing traffic. The installation has been done with Police dept. cooperation once the authorization delivered by the Road Authorities (Ministry of Transport, Highway directorate, Ministry of Interior).

Cost components:

Equipment cost: On the Belgian market, such a portable display cost between 3.000€ to 4.000€, depending on the power supply solution. The system is easy to handle and therefore installation and removal costs likely remain limited to 2 to 4 person.days per unit installed. The maintenance cost highly depends on the electric power solution and on the operational duration (estimated to max ½ person.day per week if batteries are used).

Renting solutions are also possible and would cost around 500€/750€ per week/for 2 weeks (installation and removal costs included).

Questions to be further studied/discussed:

Alternative location should be further studied; i.e. would such a system be more effective if installed closer to the transition area? The temporal and spatial effect along road works should also be investigated; as well as the effect of this measure on non-motorway road work sites should be investigated.

8. Trailer carrying a Variable Message Sign (work zone)

Characteristics (Message/Sign showed):

A trailer equipped with VMS and speed detection has been tested along the CZ motorway (towards Brno) and its impact quantified compared to a reference situation (fixed signs only). The VMS trailer was installed on the right side of the temporary traffic lanes.

Two warning displays were tested: current speed + message “Reduce you speed” or speed limit sign + “Reduce you speed”.

Road work main characteristics:

The traffic was guided into the right traffic lane by a system 2+2 in the direction from Brno to Prague. The traffic flow directions were separated by a temporary crash barrier. Therefore towards Brno right and left lanes were shifted to the left side of the central reserve (contraflow with a reduced width).

Deployment area (during WP4):

The VMS was deployed in the **work zone area** (towards Brno) – 400 m downstream the crossing of the central reserve.

Impact (measured) in term of speed behavior:

800 m downstream the VMS location, a slight decrease of the mean speed has been observed: -2,5 km/h (93km/h to 90,5km/h) for the lane immediately adjacent to the VMS (up to -4,5 km/h during the afternoon period).

On-site deployment issues:

The installation was realized in the work area behind the guardrails. The access to the trailer was therefore discussed with the Construction company and remained possible through an entrance at the transition area. The construction company being responsible for all equipment inside the work zone, their permission was necessary, besides the authorisation delivered by the road authorities (Ministry of Transport, Highway directorate, Ministry of Interior).

Cost components:

The trailer costs around 80.000€ (up to 100.000€ if a license plate recognition system is integrated to the full LED PMV).

Operational cost are mainly related to diesel consumption (90 liters per month), data communication (SIM card and CDMA – in total 50 €/month).

Questions to be further studied/discussed:

As for the portable display alternative location could be and spatial and temporal effect along road works investigated. This trailer may prove to be effective on non-motorway road work sites.

9. Police presence

Characteristics:

A Police patrol was present on site (at a fixed location) every day from 9:30 till 10:30.

Road work main characteristics:

The traffic was guided into the right traffic lane by a system 2+2 in the direction from Brno to Prague. The traffic flow directions were separated by a temporary crash barrier. Therefore towards Prague right and left lanes were shifted to the right (with a reduced width).

Deployment area (during WP4):

The Police patrol stopped in the **work zone area** (towards Prague) – 8300 m downstream the lane shift and 100m downstream the detector.

Impact (measured) in term of speed behavior:

A limited impact has been observed in the area close to Police patrol: max 2km/h (from 93,5km/h to 91,5 km/h on average; Speed limit was 80 km/h).

On-site deployment issues:

Cooperation with the traffic Police has been established at the very beginning of the project. Main issues concerned the need to provide a safe stop place for the Police patrol and what action was needed from the patrol. During the showcase the patrol was simple present and visible but did carry out any speed control (for which strict parking conditions must be met).

Cost components:

Patrolling action is part of the tasks executed by the traffic Police. The implementation of this measure doesn't cause any additional cost per se as it mainly consists in a reorganization of the patrolling task. However the setup of dedicated parking places may cause small additional costs (equipment to protect the patrol).

Questions to be further studied/discussed:

Police actions are usually reported as effective for managing speed along road work sites. This measure, combined with adequate road users information and punctual or medium-term enforcement may be further studied. The temporal and spatial effect along road works should also be investigated; as well as the effect of this measure on non-motorway road work sites.

10. Automated speed camera

Characteristics:

An automated speed camera has been deployed on-site during one of the speed monitoring campaign carried out in Belgium (cf. chapter 3.4.2.2). The camera consists in a semi mobile system installed on a fixed location along the road works, for several days. It controls speeds of all the detected vehicles and record information about over-speeding ones. This information is automatically forwarded to the Police who deliver fines.

Road users were informed by a permanent sign about the likeliness of speed enforcement. Some comparative analysis between reference and deployment period were made during WP4.

Road work main characteristics:

The temporary traffic management consisted in keeping two lanes open in each direction. The traffic has been deviated to the hard shoulder lane (around 4m width; giving access to the three interchanges and the two rest areas located along the work zone) and to a contraflow lane (around 3.25m width) separated to the opposite traffic flow by a continuous safety barrier. On both lanes, the speed along the work zone was limited to 70 km/h. The speed limit in the transition area (50m long opening in the central reserve) was 50km/h.

Deployment area (during WP4):

The speed camera has been deployed first in the transition area – 1000 m upstream the crossing of the central reserve and, secondly along the work zone – 6300 m downstream the central reserve crossing.

Impact (measured) in term of speed behavior:

For one speed monitoring device, i.e. corresponding to the monitoring site that was located 8 km downstream the crossing of the central reserve, 9,1 km downstream the Automatic speed camera deployed during Period 1 and 1,75 km downstream the Automatic speed camera deployed during Period 3, the presence of the Automatic Speed camera seems to have an impact on the average 5 minutes mean speed and on the proportion of drivers exceeding the temporary speed limit. This is particularly visible for daytime traffic (chapter 3.5.2.2). However this trend is not confirmed on the two other monitoring locations. It is therefore supposed the speed camera has a local impact that decreases when progressing along the RW.

On-site deployment issues:

Once its location and deployment period was fixed by the Police and Road work manager, the camera was installed on site by an experienced private company (with dedicated signing if needed). For evaluation purpose a good communication flow between the on-site actors and the research organization is absolutely necessary, particularly because the speed monitoring devices must be appropriately located and operational at right time.

Cost components:

From known experience, renting solutions are usually preferred for the deployment of such speed cameras. In Belgium a contract is established between the road administration and a service provider who rent, deploys the device on site and eventually delivers dedicated statistics.

All prosecutions activities are in charge of the traffic Police, for which the installation of such a system may significantly increase the work load (due to the number of violations). The setup of dedicated places may cause small additional costs (equipment to protect the device from errant vehicles).

Questions to be further studied/discussed:

The two more critical elements related to speed enforcement are the location from which the control is executed and its temporal and spatial effects (along road works). Both aspects should be further investigated to be able to draft comprehensive conclusions.

11. Combination of measures

Characteristics:

A speed monitoring campaign has been carried out along the A21/E34 motorway in Belgium where important road works were going-on. On this site an interesting combination of devices was installed along the advanced warning and transition areas (VMS, temporary gantry, speed display, rumble strips) to warn and inform drivers about the road work layout, their speed or about the accessible exits along the work zone. However no variation occurred in the deployment of these devices during the monitoring campaign.

The driven speeds have been monitored during several days and for two periods.

Road work main characteristics:

The temporary traffic management consisted in keeping two lanes open in each direction (4+0). As illustrated in chapter 3.4.3.1, the whole traffic (4 lanes) has been deviated to the side of the motorway that was free of works. The right and left lanes were respectively 2.75m and 2,50m wide.

Deployment area (during WP4):

A combination of devices was installed along the advanced warning (VMS trailer, temporary gantry) and transition areas (speed display, rumble strips).

Impact (measured) in term of speed behavior:

Speed was monitored across two consecutive periods; each characterized by a particular road work layout; i.e. by a crossing of the central reserve – speed recorded 250m upstream of the deviation; and stage 2 by a shift of the trafficked lane to the right – speed recorded 50m upstream of the lane shift.

Speed data recorded 250m upstream of the crossing of the central reserve remain close to the speed limit (higher speeds being recorded on the left lane) for both layouts/periods. For both layouts/periods the speed variance at this location remains quite low; showing a relatively homogeneous speed behavior on both lanes.

It appears clearly that driven speed seems to be very much influenced by the distance to the lane deviation; the closer is the lane deviation, the slower is the traffic; and this independently of the type of road work layout.

On-site deployment issues:

As the deployment was embedded in the road work program, no issues have been identified during WP4.

Cost components:

No information collected at this stage.

Questions to be further studied/discussed:

Based on WP4 experience, it is suggested to program additional investigation about the speed behavior in presence of a longer/70km/h crossing of the central reserve in comparison to a short/50km/h one.

It is also necessary to perform an evaluation (spatial & temporal effect) of the effectiveness of an automatic speed camera in addition to the speed management methods already used (transversal rumble strips, speed display, temporary signing gantry, VMS trailer).

When evaluating on-site showcases additional external parameters should be considered in the process to better understand the traffic and speed behavior (e.g. weather, activity on the work zone, queuing start and end) and tracking the traffic condition to fine tune the data filtering (to exclude strongly impacted traffic flow).

4.3 Some learnings about data collection and testing sites

This chapter intends to list challenging issues the ASAP partners met during the showcase and to suggest potential solutions to mitigate risk in any future speed monitoring campaigns or pilot testing of speed management measures.

Challenges:

- On site data collect remains a difficult task and may lead to missed monitoring time slots; for several reasons: installation and management of monitoring devices in a road work environment, power supply, sensor calibration;
- Deployment of speed management measures isn't easy to coordinate, particularly for testing and evaluation purposes;
- As many actors may be concerned (road (work) manager, Police department, road work contractor, data collection responsible, speed management equipment owner, etc.) communication is a major issue;
- Due to the reduction of capacity and/or work activity unfavorable traffic conditions may occur (i.e. queuing at speed monitoring location) and impact on the data quality (non-free flow speeds, non- or bad vehicle detection);
- Using on-spot speed monitoring devices and short-term monitoring campaigns may raise questions about the spatial and temporal representativeness of the evaluation results.

Ways for risk mitigation:

- Fundamental cooperation with the Road authority, Police department at strategic and operational level (road work manager, contractor, local service) to identify and commit the various actors to the project objective;
- Set up of communication and operational plans at the early stage of the road work planning to schedule the deployment of equipment, to efficiently operate the various devices and organize the data collection;
- Favor autonomous solutions for electric supply and remote device control to detect any power and sensor failure and, if not possible, schedule regular site visits by technicians;
- Define the location for the test precisely, before proceeding with the measurements. In particular detection of free flow speeds need to be investigated far away from work zones in areas of very low risk of congestions;
- Schedule traffic condition observations to facilitate the assessment of the data quality or even any further filtering of the data collected;
- Calibrate all detectors on-site during installation and at representative conditions, regularly cross-check data sets and recalibrate if necessary;
- Mix on-spot speed monitoring techniques with section based devices and favor medium to long term campaigns, including repetition into the testing protocol.

5 STAKEHOLDER'S SURVEY

The main objective of the ASAP project is to gather knowledge on effective speed management measures through road works zones. Understanding the best methods of controlling speeding in work zones includes caring for the safety of road workers, and to consider the interaction with road users. A comprehensive approach has to consider not only published research but also data from national measurements and knowledge from national experts. Hence, gathering national expertise, and practitioners, and stakeholder consultations will lead to recommendations as to how to effectively manage speed through road works zones.

The work package 4 concerns field showcase and stakeholders consultation about low cost speed management methods. This chapter deals with two of the tasks in WP4:

- Create a **strategy and priority list** for the different parameters and issues necessary for developing speed management plans for work zones (task 4.1)
- Organise a **consultation** of the stakeholders to assess the first stage of recommendations (task 4.4)

5.1 Aim

The aim was to ensure that the correct document format is being prepared to validate the first steps of the development of a framework for European Speed Management Guidelines. Hence, a consultation with the national representatives was carried out. Organizing a consultation of the stakeholders (such as representatives from the NRAs, and other experts) assesses the first stage of recommendations that will be delivered during WP5.

5.2 Method and implementation

The review of existing literature and national guidelines on speed management methods in work package 2 identified a wide variation in the factors used in guidelines to set work zone speed limits. The common parameters were identified in work package 3 and were used when constructing a targeted stakeholder survey of NRAs and road operators. The questionnaire can be found in appendix 4. The survey was used to understand the interpretation of the existing guideline factors and what could be used in future guidelines. Furthermore the results of the questionnaire were discussed among the ASAP partners and a group of stakeholders during a webinar. Moreover an American expert was consulted on the topic graduated penalties. Altogether the results were analyzed and are reported in the following chapter.

The aim was to produce a structure for work zone speed management.

In the consultation the stakeholders were not asked to determine the safe speeds. Instead, questions of interest were

- How do you want to set safe speeds with respect to
  - What parameters to consider?
  - What conditions require lower speeds?
- How should guidelines be used?

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All partners were asked to send out this questionnaire and a list of suggested contacts in a number of European countries was set up. Each partner was assigned stakeholders that they should contact. They should distribute the questionnaire and inform about the webinar to be held on June 16th. In the questionnaire there was included a reminder that we would like the respondents to participate in a follow up discussion in this webinar.

Hence, in May this stakeholder's questionnaire was sent out by the partners in e-mail to NRAs, road operators and contractors. In all, 14 European countries were contacted and a number of questionnaires were sent to each country. In return the ASAP project received 16 completed forms. The respondents represent 9 different countries. Among them there were representatives of national, regional and local authorities as well as road operators and contractors. They were all invited to the webinar, but unfortunately many of them were not able to attend the meeting due to other obligations the given date.

Descriptive statistics from the questionnaire responses were produced and preliminary results were prepared. The agenda for the webinar was

1) Introduction - ASAP project
2) Objectives for guidelines
3) Result of survey
4) Open discussion of guideline and its application

The 2 hour webinar was attended by eight ASAP members and five NRA and contractor representatives. The project manager presented the ASAP project and the results from the questionnaire, and some questions had been prepared that were put to the participants. There was also time for further discussions.

Since the European stakeholders had little experience from graduated penalties this issue was further seen into through an interview with an American expert on work zone safety.

5.3 Results from questionnaire

In work package 2 a list of parameters used in guidelines was constructed. In the list the criteria that can be identified as most common when setting speed limit in work zones are written in bold letters.

- **Type of road**
- **Original posted speed limit**
- **Presence of workers**
- **Proximity of workers to traffic**
- **Duration of road works**
- Reduction of lane widths in the work zone
- Reduction in number of lanes
- Changes in road surface properties
- Presence of crossovers

This list was used as input to the questionnaire that was designed. In the following part of the text the results from this questionnaire are presented. Each question (Q1–Q9) is presented and is followed by some descriptive statistics.

5.3.1 Questions on Guideline Inputs

There were three questions on guideline inputs (Q1–Q3). In the first question the stakeholders were asked to identify; what factors are the most safety critical, who do they affect, and in which manner do they affect safety.

Q1) A number of factors, listed below, were identified in a review of national guidelines and are candidates to define a work zone speed limit. Identify which factors are the most safety critical, who they affect, and in which manner they affect safety.			
Criteria	**Critical for safety**		
	yes	**no**	**unknown**
Original posted speed	**15**	1	0
Road type	7	7	2
Lane width	**12**	4	0
Lenght (km) of construction	7	7	2
Duration of construction	6	8	2
Workers present	**12**	3	1
Proximity of workers to traffic	**15**	0	1
Impact on Traffic (flow)	**12**	2	2
Changeovers and crossovers	**12**	2	2
Change in road surface properties	8	6	2
Use of protective barrier (Vehicle restraint system)	**11**	3	2

There were two criteria that most stakeholders could agree were critical for safety; original posted speed and proximity of workers to traffic. The vast majority also agreed on the factors lane width, workers present, impact on traffic flow, changeovers and crossovers, and the use of protective barriers.

In the next question they were asked how they would like to use the identified factors to set a work zone speed limit.

Q2) How would you like to use the factors listed in Question 1) to set a work zone speed limit?	Number of answers
i) Flow chart or other step by step procedure, requires little subjective judgment	3
ii) Reference information: A table with general suggestions for different situations, requires some judgment	**9**
iii) Engineering judgment: Technical documentation is provided and local engineers independently choose speed limits	2
iv) Other (explain)	0
All	14
Missing	2

The majority of the stakeholders wanted a table with general suggestions for different situations, which requires some level of judgment from the user.

We also wanted to know if they had any formal procedures for setting work zone speed limits.

Q3) Does your country or organization have a formal procedure for establishing a work zone speed limit?	Number of answers
Yes - There is a formal process and predetermined speed limits	**13**
No - There are guidelines but each work zone is subjectively assessed	1
Unknown	2
All	16
Missing	0

Most countries seem to have a formal process for establishing a work zone speed limit, and they also have predetermined speed limits.

5.3.2 Questions on speed control

There were two questions on speed control; if there were a procedure for selecting speed management measures (Q4) and if there were guidelines for enforcement of speeds in work zones (Q5)

Q4) When you have a work zone speed limit decided, do you have a procedure for selecting speed management measures?	Number of answers
Yes - There are recommended speed management methods for work zone speed limits	9
No – Speed management methods are selected independent of the work zone speed limit process	7
All	16
Missing	0

Q5) Are there guidelines for the use of enforcement to control speed in work zones?	Number of answers
Yes – The road authority / work zone contractor influences speed enforcement	8
No – The road authority / work zone contractor has no influence on speed enforcement	8
All	16
Missing	0

Somewhat half of the respondents agreed to the statement that there are recommended speed management methods for the decided work zone speed limit while the other half claimed that those methods are selected independent of the work zone speed limit process.

Half of the respondents meant that there are guidelines for the use of enforcement in work zones and that the road authority or the work zone contractor can influence the speed enforcement. The other half of the respondents disagreed to that.

5.3.3 Questions on Work Zone Type / Area

Two questions concerned the work zone area (Q6 and Q8). It was of interest to know if there are separate guidelines for the speed management in the entrance, exit and transition areas (Q6), and for mobile workzones (Q8).

Q6) Does the periphery (entrance, exit, and transitions to normal traffic conditions) of the work zone have separate guidelines for speed management?	Number of answers
i) the entrance/exit of the work zone has separate guidelines to establish speed limits	0
ii) the entrance/exit of the work zone is included in the work zone speed limit guidelines	**11**
iii) there are no explicit guidelines for the entrance/exit of the work zone	1
All	12
Missing	4

Q8) Do mobile work zones have separate guidelines for speed limits?	Number of answers
Mobile work zones have **identical speed limit requirements** as fixed work zones	6
Mobile work zones have **different speed limit requirements** from fixed work zones	10
All	16
Missing	0

In most countries the periphery of the work zone does not have separate guidelines to establish speed limits. Instead those are included in the work zone speed limit guidelines. One question of interest is then what distances are used in the transitions from regular traffic to work zone speeds?

Most respondents agreed that mobile work zones **have different speed limit requirements** from fixed work zones, although some meant that they were identical. This does not give any indication whether the speed limits are higher or lower than those at fixed work zones.

5.3.4 Basis for Decisions

In the questionnaire to the stakeholders there were also a question on what sources of data that are used when evaluating work zone safety (Q7) and on who the end-users of the ASAP guidelines are (Q9)

Q7) What sources of data are used to develop and follow up work zone safety and speed management methods?	Number of answers
National data sources (police, hospital data, road authority) Specific data collected by work zone contractor Data from national and contractors No data were available	5 2 0 **8**
Unknown	1
All	16
Missing	0

Q9) Who are the end users that you would like to give ASAP guidelines? (multiple responses were allowed)	Number of answers
National Road Authorities (national and regional offices) Road work contractors - Engineers/Management Road work contractors - Road workers Police / Speed Enforcement	13 9 8 9

The answers from the stakeholders mainly show that either no data are available to develop and follow up work zone safety and speed management methods, or national data sources are used. The end users were identified to be the NRAs but also road work contractors, engineers, management, road workers and the police.

To sum up, there was no definite confirmation from respondents that the listed factors are the most critical, although some stood out as more critical than others. Furthermore it was made clear that the ASAP guidelines are not expected, nor requested to replace existing guidelines. The information from ASAP was instead regarded as an important support document for existing guidelines and as useful input to future revisions of the connected relevant guidelines.

Alarmingly, half of the respondents reported that there are no data available to develop and follow up work zone safety and speed management methods.

5.4 Results from webinar

The webinar was attended by a few, but keen NRA and contractor representatives and by representatives for all ASAP partners. This formed an intimate group and gave plenty of space for open-hearted discussions. The partners represent Austria, Belgium, The Czech Republic, Italy and Sweden while the attending stakeholders represent France, Luxembourg and Sweden.

The project manager introduced the ASAP project and the findings from work package 2 and 3. The results from the questionnaire were presented and some questions were put to the participants. One of the questions that was discussed was the speed reductions in the transit zone. It turned out that in France these start at 800 ahead of the work zone, and are usually reduced in steps of 20 km/h (110-90-70-50) but sometimes from 90 to 50. In Luxembourg the transit zone is included in the guidelines. On motorways the speed reduction starts 800-1000 m before the work zone and speed is reduced in steps (130-90-70). In Sweden the transit zone length is related to the number of speed reductions, where each reduction is 200 meters long. Commonly used steps are 110-90-70, but 80-50 is also used.

In France many mobile speed cameras are being introduced and the road operators have control of enforcement. In Sweden the road operator has no such control. Instead they take physical measures such as chicanes to achieve an appropriate speed level through work zones.

When discussing mobile work zones it turned out that such work zones do usually have lower speed limits than fixed work zones, due to people on the road. This was the case both in Sweden, Luxembourg and France.

As described, the presentations were followed by a long and interesting discussion about the results and what kind of information the stakeholders could benefit from. The meeting seemed to agree with the findings in the questionnaire and the conclusions drawn by the project team that a check list in a stand-alone-document would be useful. The stakeholders also expressed the opinion that the results from ASAP can be useful not only for national road administrations and contractors but also for transit traffic and municipalities.

5.5 Results from interview

5.5.1 Graduated penalties in work zones

In July 2014, an interview was conducted with the chair of the TRB sub-committee: Positive Protection in Work Zones[11], research engineer Melisa Finley from the Texas Transport Institute (TTI). This US expert on work zone safety reported similar experiences from graduated penalties as reported in ASAP D2.1, Chapter 5. There are difficulties in interpreting the results from different states and there are no standardized results available. Furthermore it is difficult to connect results in Table 5-1, ASAP deliverable D2.1 to the effect of an extra sign informing about doubled fine. This is due to the following:

- People are not aware of the original level of the fine for speeding, meaning that information about a double fine at work zones is confusing for the drivers.
- The administration regarding the fines is not consequent between work zones. Fines are not always sent out.
- The levels of the fine differ between states.

Melisa Finley draws a parallel to the American experience for signing. Passive signs are less effective than variable message signs because with the passive sign the driver does not see any direct consequence of their speeding behaviour in the work zone whereas actively informing the driver of their actual speed on variable message signs (direct feedback) has a larger effect. To be effective the graduated fixed penalties must be perceived as being actively enforced and the consequences must be known, Finley concludes.

5.5.2 Lack of data

American work zone safety expert Melisa Finley confirmed that it is difficult to find speed data from work zones. This was also the experience from ASAP deliverable 2.1 and 3.1. She was not aware of any complementary US data useful for the ASAP project and the limited data

[11] under the TRB committee on work zones

available is more than 10 years old. There are, however, some planned activities concerning work zones in the US; a new project about “Work zone speed data and crash data practices” is about to start.

5.6 Conclusion from the stakeholders consultation

The results of the ASAP project should be distributed to the appropriate users and in a form that is most suitable for application. The scope of the ASAP results must be taken in the context of work zone design procedures, national laws, and the responsibilities of third parties such as the police, construction companies, etc.

Although there were some critical factors that almost all agreed on, there was no total confirmation from the queried experts that the existing factors are the most critical. It was made clear both in the questionnaire responses and during the webinar that the ASAP guidelines are not expected, nor requested to replace existing guidelines. The information from ASAP was instead regarded as an important support document for existing guidelines and as useful input to future revisions of the connected relevant guidelines.

Setting the speed limits does not guarantee a low speed in work zones. In the literature review, the Danish guidelines gave a method to check current speed level at work zones; simply by using a stop watch (i.e. in the cell phone) to measure the time travelled a given distance, and to calculate the speed for a number of vehicles. If the speed level is too high, complementary measures have to be taken that can assure a sufficiently low vehicle speed. Speed cameras and physical reductions give examples on such measures. When it comes to graduated penalties there are difficulties in interpreting the results from different states in the USA and no standardized results are available. There are several conditions that has to be fulfilled, such as

- Drivers have to be aware of the amount of the fine
- The amount of the fine has to be perceived as deterrent
- The administration of the fines has to be successful.

Hence, this measure cannot be recommended as a stand-alone measure but has to be combined with other measures such as information about the amount of the fine for speeding in work zones, and the risk of being fined has to be perceived as high.

Considering the results, the ASAP guidelines are most appropriate to be packaged as a stand-alone reference guide/text document. The approach will thus be to develop a “check list” where current guidelines can be applied at a site. ASAP results can be used as quality assurance that the work zone speed is appropriate.

Many countries do not have detailed data available for assessing work zone safety and ASAPs experience in data collection in the data review (WP3) and field showcases (WP4) will be important resources for future users. Moreover, the planned activities concerning work zones in the US; a new project about “Work zone speed data and crash data practices” that is about to start; could be of interest for the CEDR organization.

The ASAP project should provide a guide not for setting the speed limit but for choosing the best speed reducing methods that will result in appropriate speed in work zones. Appropriate speed is achieved when; the desired speed is achieved, speed variance is low, and when accident and injury rate is low. Desired speed might be the speed limit through the work zone, but can as well be the recommended speed or the speed level expected from the speed reducing measures. Level of desired speed should never be higher than the speed limit.

The objective of the ASAP project is to consider appropriate speeds and ignore capacity and construction needs. Assuming that the work zone is predefined, this only causes for assigning the speed management measure(s). This procedure can be illustrated as in the **Figure 88**.

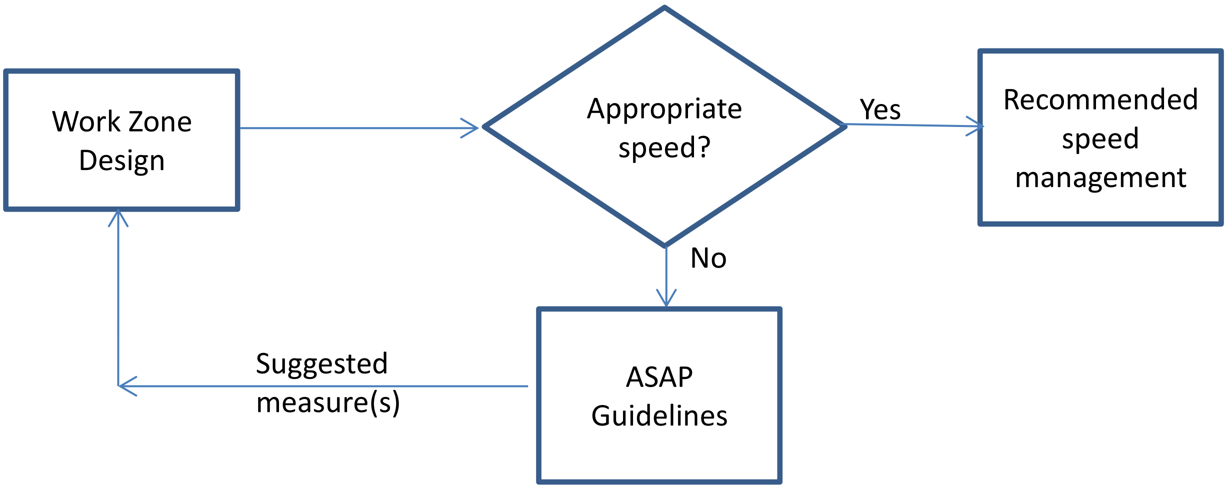

Figure 88: Procedure of assessing appropriate speed in work zones

6 ACKNOWLEDGEMENT

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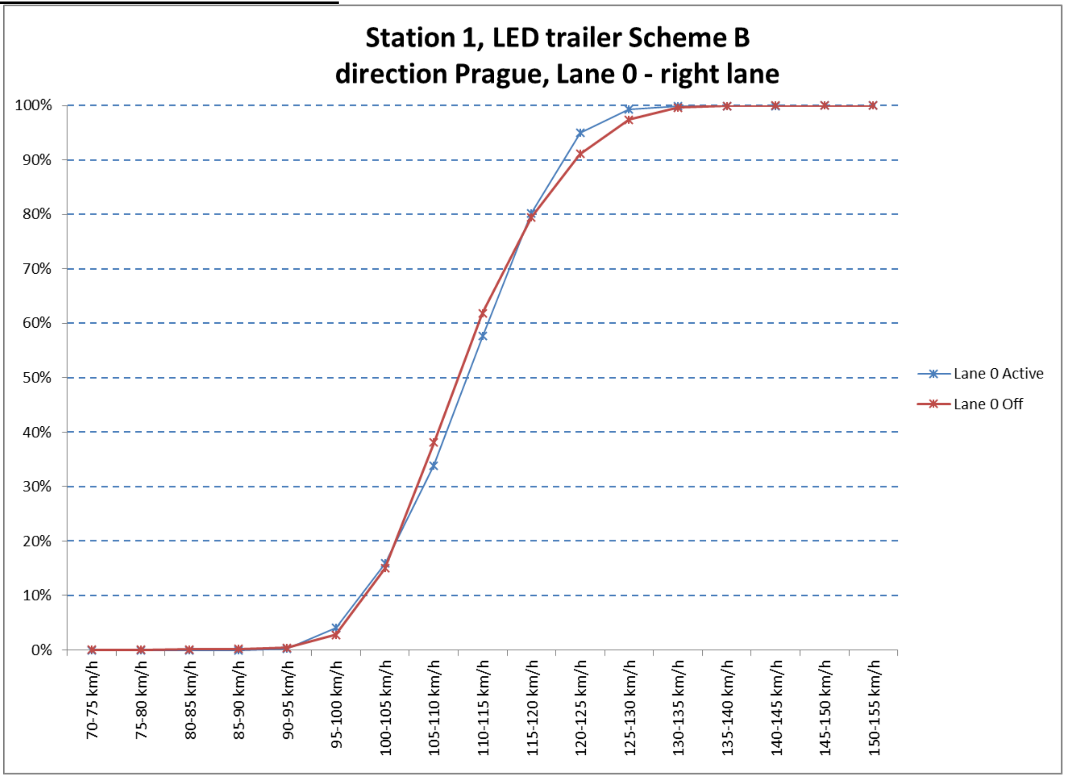
The different showcases carried out under this practical work package would have been possible without the great cooperation of the road authorities where the field testing took place. The partners would particularly like to thank the Czech Road Authority, The Flemish Road Authority (Belgium), The Walloon Road Authority (Belgium) for their support, their commitment and the resources they dedicated to support the ASAP project.

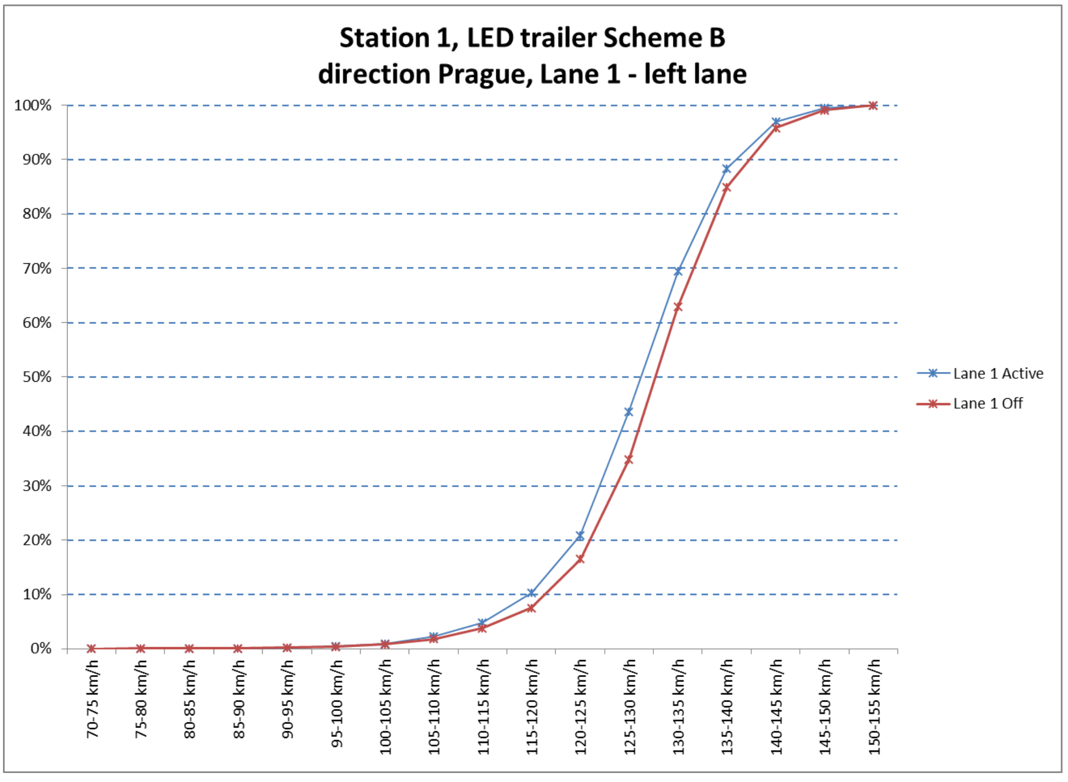
APPENDIX

Appendix 1 – D1 Motorway (CZ): 8 detailed test schemes

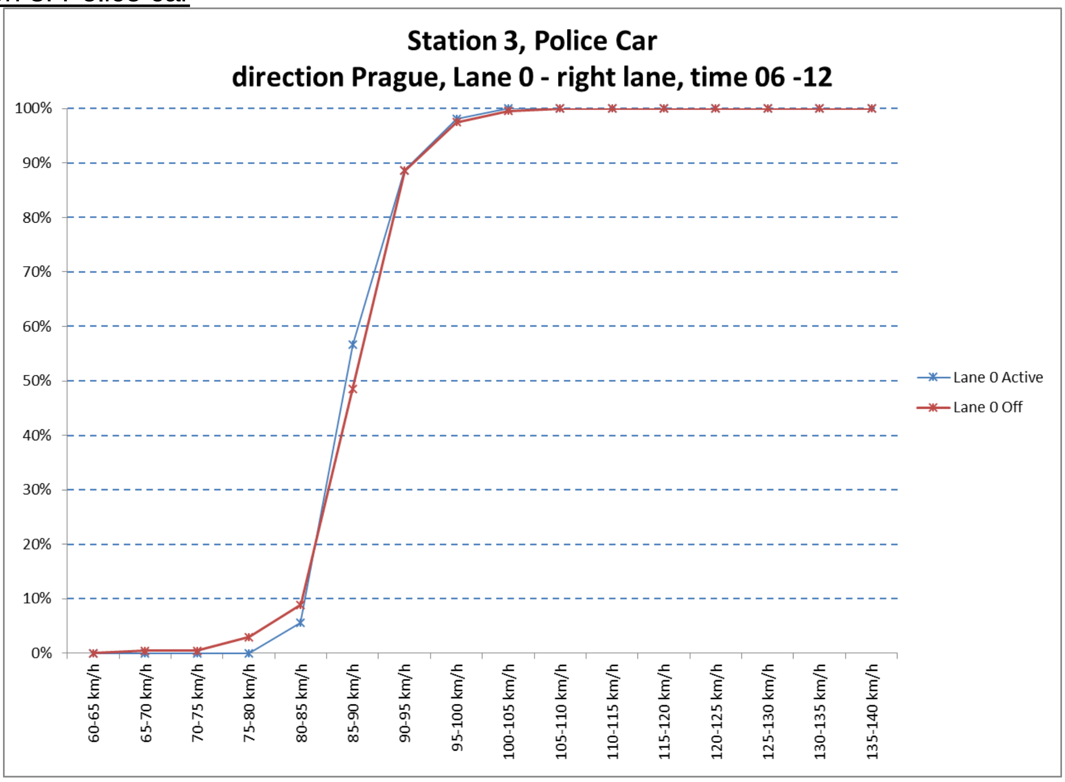
Appendix 2 – D1 Motorway (CZ): Speed distributions (in addition to chapter 3.5.1)

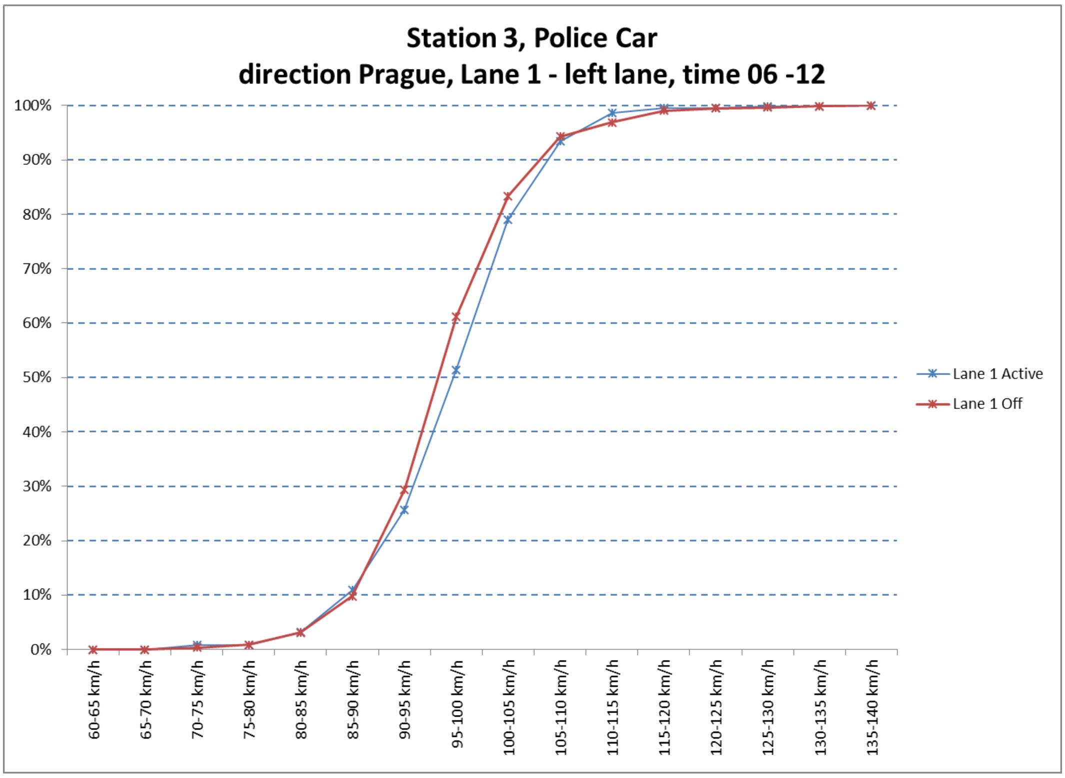
Station 1: LED trailer scheme B





Station 3: Police car

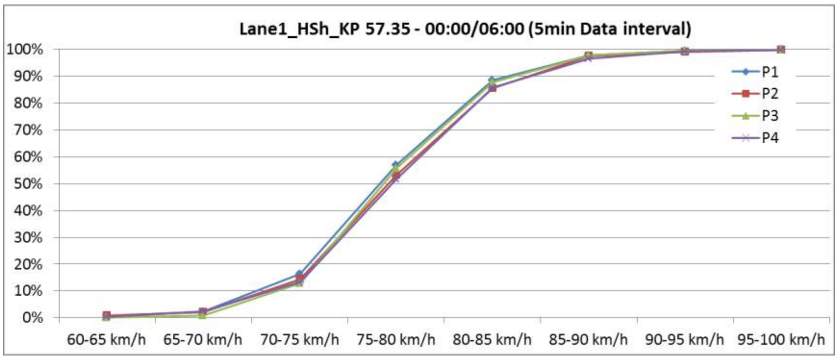




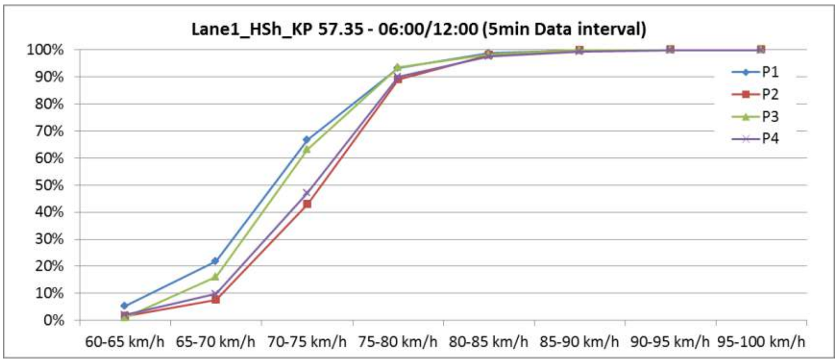
Appendix 3 – Motorway A15/E42 (BE, section Daussoulx-Sambreville) - Results from speed monitoring along the work zone

Cumulative speed distribution at KP57.35 (Traffic on the shoulder lane)

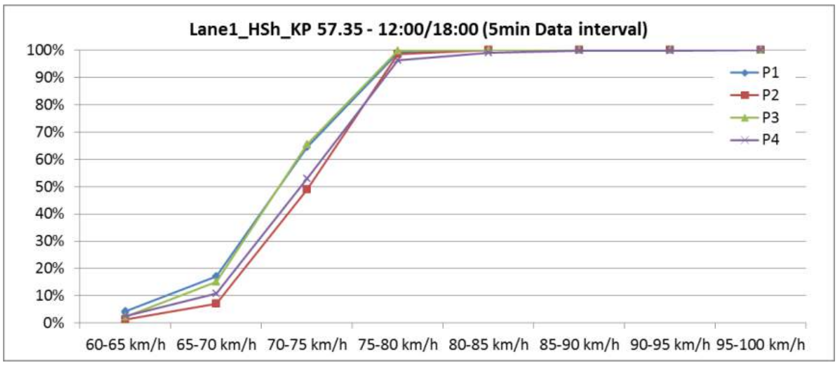
- 00h - 06h:



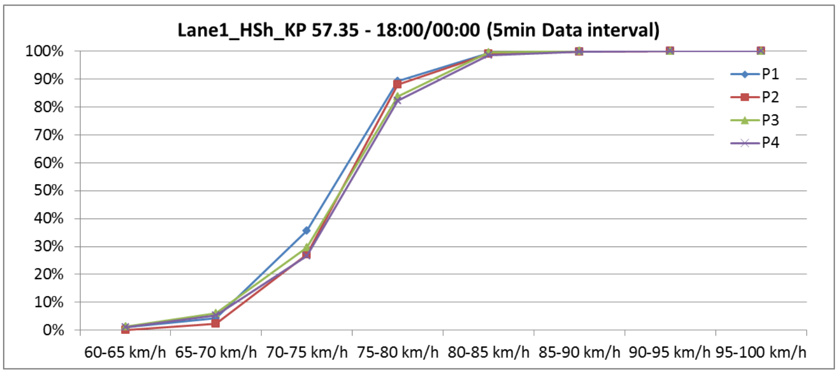
- 06h - 12h:



- 12h – 18h:

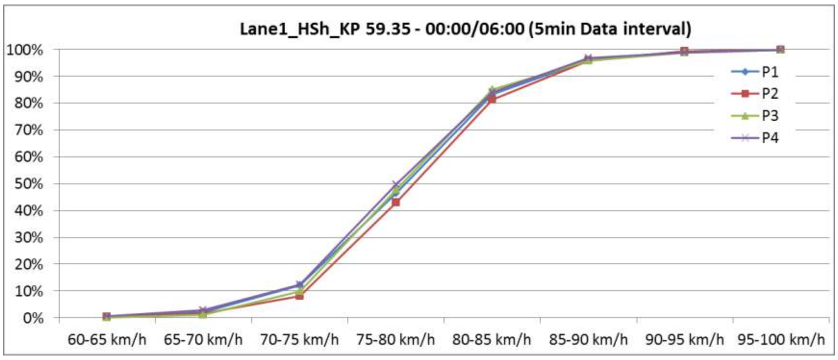


- 18h – 24h:

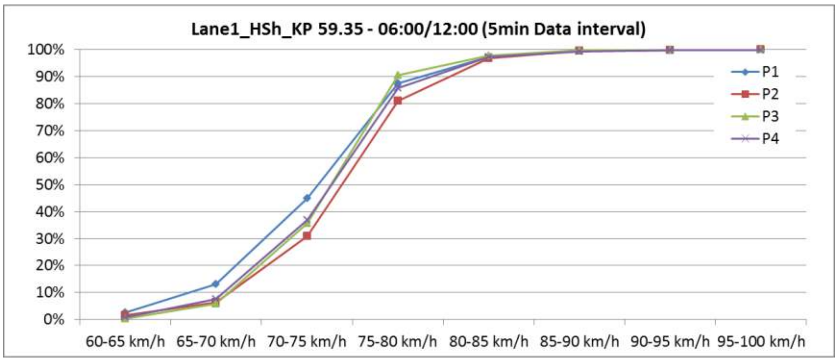


Cumulative speed distribution at KP59.35 (Traffic on the shoulder lane)

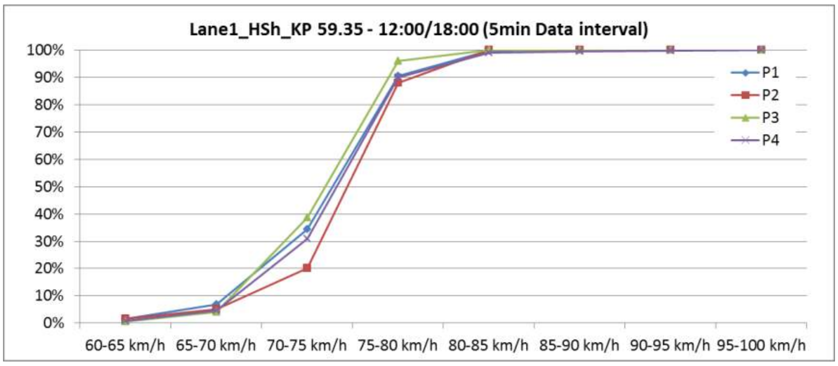
- 00h - 06h:



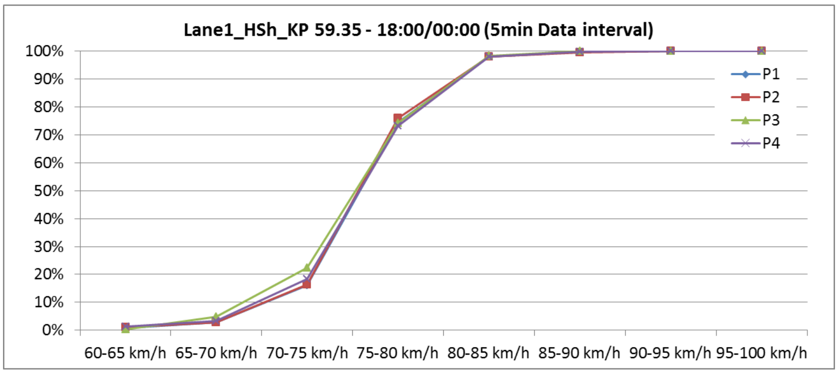
- 06h - 12h:



- 12h – 18h:

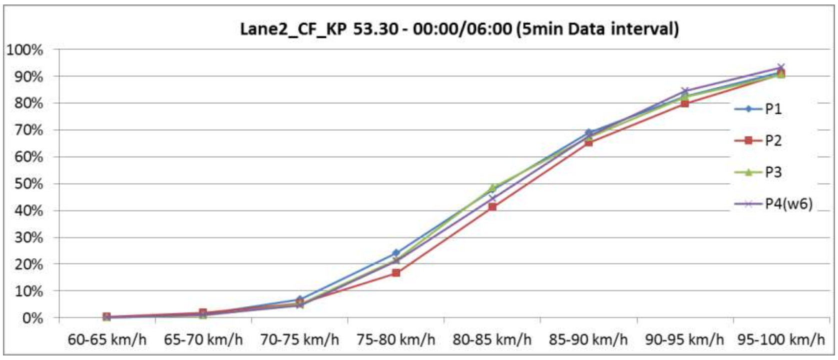


- 18h – 24h:

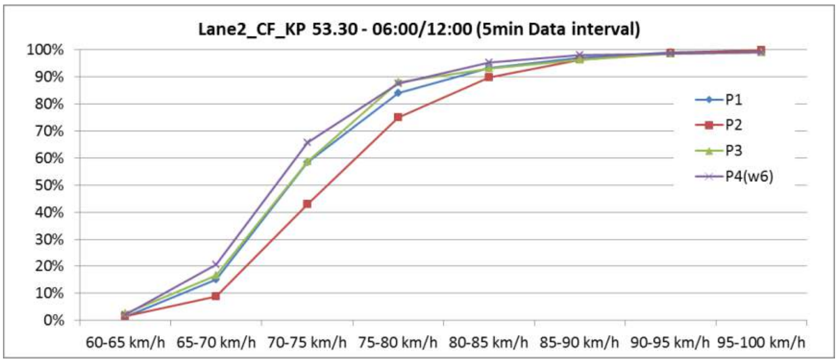


Cumulative speed distribution at KP53.30 (Traffic on the shoulder lane)

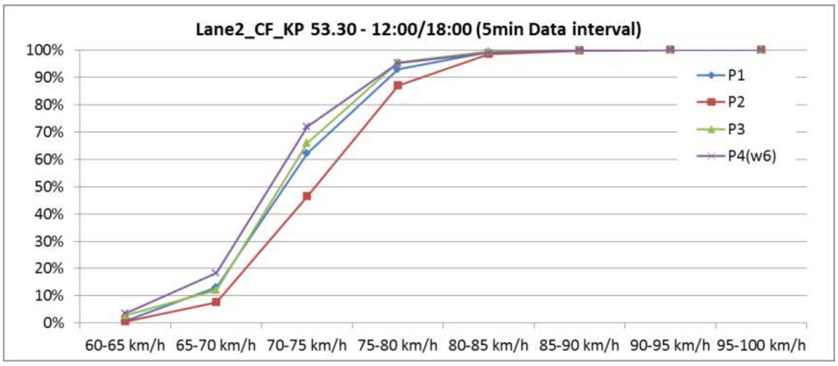
- 00h - 06h:



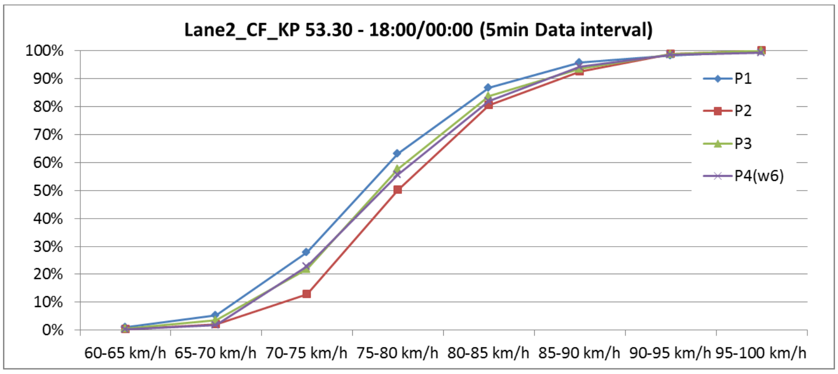
- 06h - 12h:



- 12h – 18h:



- 18h – 24h:



Appendix 4 – Questionnaire used for the stakeholders' consultation

Stakeholder Survey on Work Zone Speed Limits
Establishing the outputs for the Appropriate Speed Saves All People (ASAP) Project
(Project information at asap.fehrl.org)

The Conference of European Directors of Roads (CEDR) sponsored the ASAP project to review speed management issues in road work zones and develop guidelines for setting safe speed limits for road users and road workers. After a review of existing literature we would like your feedback on the following information and your participation in a follow up discussion in a webinar or webmeeting.

The following questions have been developed after reviewing the existing guidelines and work zone safety literature. A number of parameters are used in the national guidelines but it is not possible to clearly identify a set of parameters that are common in all countries.

ASAP is focusing on safety guidelines and will not develop work layout, construction, or traffic management guidelines. Consider the following questions from a purely safety perspective.

Q1) A number of factors, listed below, were identified in a review of national guidelines and are candidates to define a work zone speed limit. Identify which factors are the most safety critical, who they affect, and in which manner they affect safety

Critieria	Critical for Safety	Affect Road User/ Road Worker	Safety Issue	Comment
Original Posted Speed				
Road Type				
Lane Width				
Length (distance) of Construction				
Duration (Time frame) of Construction				
Workers Present				
Proximity of Workers to Traffic				
Impact on Traffic (flow)				
Changeovers and Crossovers				
Change in Road Surface Properties				
Use of protective barrier (Vehicle Restraint System)				
Other , *specify*				

Q2) How would you like to use the factors listed in Question 1) to set a work zone speed limit?

Answer

Any Comments

Q3) Does your country or organisation have a formal procedure for establishing a work zone speed limit?

Answer

if yes

Q4) When you have a work zone speed limit decided, do you have a procedure for selecting speed management measures?

Answer

Q5) Are there guidelines for the use of enforcement to control speed in workzones?

Answer

Q6) Does the periphery (entrance, exit, and transitions to normal traffic conditions) of the work zone have separate guidelines for speed management?

Answer

Q7) What sources of data are used to develop and followup work zone safety and speed management methods?

Answer

(Note that the CEDR sponsored project "BROWSER" is investigating work zone data sources)

Q8) Do mobile work zones have separate guidelines for speed limits?

Q9) Who are the end users that you would like to give ASAP guidelines?
(Choose all groups of interest)

Other *(please describe)*