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IRIS

Incursion Reduction to Increase Safety in road work zones

Road Safety Management at Work Zones – Final report

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Incursion Reduction to Increase Safety in road work zones

D3.2 Road Safety Management at Work Zones – Final report

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Abbreviations

ASFA	Association des Sociétés Françaises d'Autoroutes
ATSSA	American Traffic Safety Services Association
CB	Cell broadcast
CEDR	Conference of European Directors of Roads
DSDS	Dynamic Speed Display Signs
EN	European Standards / European Norms
EU	European Union
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration (USA)
IAS	Intrusion Alert Systems
IGLAD	Initiative for the Global harmonization of Accident Data
IPV	Impact Protection Vehicle
ITS	Intelligent Transport Systems
LED	Light Emitting Diode
MASH	Manual for Assessing Hardware (USA)
NCHRP	National Cooperative Highway Research Program (USA)
NRA	National Road Authority
PIARC	World Road Association
RSA	Road Safety Audit
RSI	Road Safety Inspection
TMP	Traffic Management Plan
TTC	Temporary Traffic Control
TTCD	Temporary Traffic Control Device
TTCP	Temporary Traffic Control Plan
TTM	Temporary Traffic Management
TMA	Truck Mounted Attenuator
UFOV	Useful Field Of View
VMS	Variable Message Signs
WZRSA	Work Zone Road Safety Audit
WZRSI	Work Zone Road Safety Inspection
WZSA	Work Zone Self-Assessment

Glossary of Terms

Auditors: Safety personnel with training and certification according to Directive 2008/96/EC of the European Parliament and of the Council on road infrastructure safety management. In this deliverable the term auditor is used for road safety experts who perform Road Safety Audits and/or Road Safety Inspections.

Road Safety Audit (RSA): A formal safety performance examination of a road or traffic project by an independent audit team. It qualitatively estimates and reports on potential road safety issues and identifies opportunities for improvements in safety for all road users.

Road Safety Inspection (RSI): A systematic, on site review, conducted by road safety expert(s), of an existing road or section of road to identify hazardous conditions, faults and deficiencies that may lead to serious accidents.

Traffic Management Plan (TMP): A formal plan defining project-specific strategies to minimize the safety and mobility impacts from the work zone on roadway users. For all projects, a TMP requires a temporary traffic control plan that addresses traffic safety and control through the work zone. For significant projects, the TMP must also contain both transportation operations and public information components.

Temporary Traffic Control (TTC): Regulating, warning, or guiding traffic through a road segment where road user conditions are changed because of a work zone or incident.

Temporary Traffic Control Device (TTCD): A sign, signal, marking, or other device used to regulate, warn, or guide traffic; placed on, over, or adjacent to a street, road, pedestrian facility, or shared-use path by authority of a public agency having jurisdiction.

Temporary Traffic Control Plan (TTCP): A plan or set of plans detailing the contracting/construction techniques, strategies, and use and location of all temporary traffic control devices that will facilitate traffic flow and safety through and around work zones.

Temporary Traffic Management (TTM): Placing, maintaining and removing of temporary traffic control devices for work zones to ensure safe, efficient and effective movement of all road users and the safety of all those working on or in the work zone.

Useful field of view (UFOV): The area in which humans can detect and process information without moving our head and eyes.

Work Zone: A segment of roadway where activity of either a short- or long-term duration, which can include a stationary or moving operation is being performed, including maintenance to existing roadways, construction of new elements, or other non-roadway work (e.g., utility installations).

Work Zone Inspection Program: Work zone safety examination involving agency level reviews and project level inspections.

Work Zone Process Review: Periodic evaluation of work zone policies, processes, procedures, and impacts of work zones that aids in the process of addressing and managing the safety and mobility impacts of work zones. The process review helps to assess the effectiveness of a program or a set of processes and procedures.

Work Zone Road Safety Audit (WZRSA): A formal safety performance evaluation that can be performed at any stage of a planned or existing work zone (project planning and design, or in active work zones) by an independent, multidisciplinary team. It qualitatively estimates and reports on potential work zone safety issues, identifies opportunities for improvements in work zone safety for all road users and workers, and culminates in the development and presentation of a final report citing work zone safety enhancement recommendations.

Work Zone Road Safety Inspection (WZRSI): A formal review of temporary traffic control devices and safety/mobility strategies deployed according to an approved plan, standards and specifications in an active work zone.

Work Zone Self-Assessment (WZSA): A tool consisting of a set of questions designed to assist those with work zone management responsibilities in assessing their policies, programs and procedures against many of the good work zone practices in use.

1 Introduction

1.1 The IRIS-project

To provide a safe and efficient road infrastructure maintenance is necessary and important. In most cases, road work zones are located close to the traffic, with limited space available. Such circumstances can lead to risks for road users and road workers, hence it is important for road authorities, work environment authorities and construction companies to minimize these risks. Despite the overall progress made by the national road authorities in improving road safety, work zone accidents in Europe remain common, work zones are hazardous for both road users and road workers as can be seen regarding the numbers of incidents collected in various countries (see e.g. Trafikverket, 2016, Slootmans & Daniels, 2017; Statens Vegvesen, 2011).

The Directive 2008/96/EC (EC, 2008) has encouraged the introduction of Road Infrastructure Safety Management tools and it requires the establishment and implementation of procedures relating to, among others, Road Safety Audit and Road Safety Inspection (RSA, RSI) by the Member States. The directive applies, however, only to roads, which are part of the trans-European road network. A recent proposal for amendment of the Directive 2008/96/EC (EC, 2019) expands the requirement to all primary roads, however, there is no specific demand for RSA or RSI concerning road work zones. Since road work zones represent elevated hazards, running systematic and effective RSA/RSI procedures is vital to provide safe environments for both road users and road workers.

The main aim of IRIS (Incursion Reduction to Increase Safety in road work zones) is to share best-practices on traffic management at work zones with national road authorities in Europe for short-, medium- and long-term road works. IRIS is commissioned by the European platform for cooperation between national road authorities (CEDR) and executed by a consortium of Lund University (Sweden), the Kuratorium für Verkehrssicherheit (Austria) and Vias institute (Belgium). Central aim of the project is to provide practical recommendations for accident prevention at work zones across Europe.

1.2 The present report

This report aims at bringing together all the findings of the various activities of the IRIS project, i.e. about principles to be considered during planning, establishment and maintenance of work zones, as well as auditing and inspecting road works. Since safety at work zones, besides road users' safety, includes aspects of work safety, issues of road worker's safety, human factors and recommendations for educational measures are also part of the report.

An analysis of recorded accidents at and around work zones was carried out. The sources used were the IGLAD database (http://www.iglad.net/) and national databases from Belgium, France, Ireland, the Netherlands, Norway, Sweden and the UK.

Psychological trends and attitudes to improve safety at work zones were studied by a literature review related to psychology of perception and attention (e.g. unintentional blindness, useful field of view, etc.), environmental psychology (e.g. automatic behavioural change) and traffic psychology (e.g. human factors with impact on traffic behaviour).

An inventory of best practices to prevent incursions into work zones as well as a review of best practices in work zone road safety audit and inspection requirements were made. Besides the systematic literature search, other available sources through knowledgeable experts in the field were used.

To gather information on guidelines, standards, strategy and procedures, interviews with stakeholders have been made in several European countries, such as Austria, Belgium, Germany, Ireland, the Netherlands, Slovenia, Sweden and the United Kingdom. These interviews resulted in a detailed overview of current practices in the selected countries.

The findings correspond to the current situation, i.e. they do not cover probable future problems like the issue of autonomous vehicles. These vehicles might pose a problem at work zones in the future, as autonomous vehicles, at current state, have difficulties in detecting road works where signage and road marking have not been sufficiently changed to reflect the layout during the work zone. On the other hand, remotely controlled vehicles and automation that can be used to reduce exposure of road workers are included as possible measures to improve safety at work zones.

Preceding this final report (deliverable D3.2) two deliverable reports and a demonstration video have been produced during the project. These deliverables are:

- D2.1 Guidance document on temporary traffic management
- D2.2 Tools for Road Safety Audits and Road Safety Inspections at Work Zones
- D3.1 Demonstration of best practice solutions of work zone safety management

All deliverables are available at the project web site: https://www.cedr-iris.eu/

2 Accidents at work zones

Work zone related accident were gathered from the IGLAD-database (Initiative for the Global harmonization of Accident Data, www.iglad.net) and the CEDR-network. Table 1 lists the reviewed accident data at work zones.

The collected data was used to provide a descriptive overview of factors related to work zone accidents. However, it has to be kept in mind that all represented datasets originate from different sources and from samples of different sizes. Consequently, these data are interesting to get an overview of background factors but are not suited to make comparisons between countries.

Table 1. Reviewed accident data at work zones.

Country	Source	Number of cases related to road works	Years	Roads	Severity*
International (data from Austria, Czech Republic, France, Germany, Italy, Sweden & Spain)	IGLAD	13	2007 - 2014	All roads	All
Belgium	Vias institute	20	2014 - 2015	Motorways	Fatal
France	Association des Sociétés Françaises d'Autoroutes (ASFA)	349	2014 - 2016	Motorways	All
Ireland	Transport Infrastructure Ireland	96	2016 - 2017	All roads	All
Netherlands	Rijkswaterstaat	37	2018	Motorways	All
Norway	Norwegian Public Roads Administration	23	2005 - 2009	All roads	Fatal
Sweden	Swedish Transport Administration	3958	2003 - 2015	All roads	Injury
United Kingdom	Highways England	2542	2016 - 2017	Motorways	All

* 'All' = no injury type specified, 'Injury' = only accidents in which at least one person was injured or killed, 'Fatal' = accidents in which at least one person was killed

In 2017, the IGLAD accident database contained 3100 cases in total. For the analysis of crashes near work zones only the cases from EU countries were considered, resulting in a subset of 2150 cases from Austria, Czech Republic, France, Germany, Italy, Spain and Sweden. The selection based on specific search terms resulted in 13 relevant crashes where a total of 33 vehicle occupants or pedestrians were involved. The most frequent accident scenarios were rear-end crashes in congestion at work zones (3 times) and 'wrong manoeuvres in changed traffic situation' (3 times).

Other sources are national studies from Belgium (Slootmans & Daniels, 2017), Norway (Statens vegvesen, 2011) and Sweden (Trafikverket, 2016). The most frequent **accident types** at work zones are **single-vehicle accidents** and **rear-end collisions**. Rear-end collisions at work zones often happen in emerging traffic jams upstream the work zone. Traffic jams at work zones usually are the consequence of work zone traffic management measures such as a reduction of the number of lanes, narrowing lanes or compulsory lane changes. Furthermore, some of the reported accidents in the mentioned sources are **collisions with safety devices** (e.g. shock absorbers, guardrails) that are put in place to protect the work zone area. A large majority of all work zone accidents happen in daylight and good weather conditions.

On Belgian motorways, 13% of all fatal accidents (20 out of 158) took place in or nearby a work zone (Slootmans & Daniels, 2017). Four accident configurations could be distinguished. The dominating type of accidents (11 accidents) were the **rear-end** collisions in a traffic jam. In the next accident type (4 accidents), a **vehicle hit a shock absorber** which announced and/or secured road works further down the motorway. The third accident type is very similar to the previous one. A driver **collided with the demarcation of the road works**. These 3 single accidents happened inside the work zone. In addition, there were 2 more accidents in which road work played a role, but less directly. In these accidents, a **driver lost his way** due to the road work, and therefore carried out a risky manoeuvre or exited the motorway at the last minute.

From the perspective of the **road workers**, work zone **incursions** (i.e. vehicles entering the work zone) are of importance. Work zone incursions are separately monitored in some countries, e.g. by Highways England (http://www.highwayssafetyhub.com/traffic-management-incursions.html). Incursions can be either intentional or unintentional. In absolute numbers, most incursions are **intentional** (e.g. a road user seeks refuge due to vehicle breakdown, a road user seeks information, a road user seeks some benefit such as a shorter distance to a service or destination). However, the most severe accidents happen in case of **unintentional** incursions such as road users following a works vehicle into the works in error, road users entering the works area as a result of confusion or road users entering the works area as a result of a collision or to avoid a collision.

None of the countries sent their work zone incident data in the EuRoWCas data format. The selection of incidents to report, the level of detail to include and the database structure differ from country to country, creating an additional difficulty while analysing the incident data.

3 Principles of safe work zones

3.1 Basic principles

3.1.1 Human factors – road users

Human factors play a significant role in driving. They influence driving behaviour and affect safety. Some of them may even be more crucial when driving in a work zone:

- **Attention**; attention is the behavioural and cognitive process of selectively concentrating on specific information, while ignoring other perceivable information
- **Divided attention**; in a traffic situation, attention is spread over all the various aspects that are relevant for the driving task, which leads to a divided attention
- **Inattention** is a general state of less attention or awareness
- **Inattentional blindness;** if a person is really focusing on a specific action (texting, telephone conversation, looking for a specific place,…) exogenous cues would not always be sufficient
- **Unintentional blindness;** causes certain events in our field of vision to go unnoticed. It is about occurrences we did not expect in a given situation and we are not focusing on. It looks as if we cannot see it, because it does not match our expectations.
- **Cognitive workload;** drivers can only handle a limited amount of information at the same time, the attention capacity has limits
- **Useful field of view (UFOV);** it means the area in which we can detect and process information without moving our head and eyes; the UFOV is narrowing with increasing speed
- **Camouflage**; impaired visual function, perceptual illusions, deterioration to perceive objects in the dark
- **Emotions**

Ullman et al. (2017) analysed work zone related accidents and the relationship between several predisposing factors, like environmental, human and vehicle variables that influence crash occurrence. As far as the human variables could be analysed from the description of the accidents, the following human factors are involved:

- **Physical condition of the driver** (health problems, fatigue, driving under the influence of alcohol/drugs)
- **Distraction of the driver** (due to physical condition, use of devices, passengers, distraction by events outside the car)
- **Confusion/uncertainty** about the situation (which lane/direction to take, restricted overview of the situation, distance challenges)

According to Ullman et al. (2018) a work zone could be seen as a latent danger in the traffic system. This is due mostly to the reduction of available space on the road – three aspects contribute to the latent danger:

- Due to reduction of space and depending on the traffic density, work zones can lead to congestion; congestion is not always expected by drivers
- Reduction of available space can require closing of lanes; temporary travel path changes might be necessary which can lead to confusion
- Lanes are often narrower, and the work zone can be close to the lane. This reduces the possibilities to manoeuvre and makes it more difficult to recover from small mistakes.

3.1.2 Human factors – road workers

Working on roads in or nearby traffic is a dangerous job. Statistics on work related accidents show a high range of accidents within construction companies (Douwes et al., 2014) although the major cause of accidents with injuries in this sector is not traffic-related (Fedris, 2017). Looking at risk sensitivity, a basic principle of our perception that in early psychological works already was described as 'habituation' (Rankin et al., 2009) comes into play. The first time a worker is exposed to traffic nearby its work zone, he will be aware of the risk. The insensitivity of risk-perception will depend on several factors as speed, proximity or even noise from traffic. Exposed daily to this risk, the worker will get familiarized and after some time, he will probably not notice the risk anymore, except in exceptional circumstances. In other words, the sensitivity of the worker for this specific risk will decrease, which can lead to misinterpretation or less careful behaviour. They do not neglect the risk, but they underestimate it (Sharot et al., 2011).

Applied to accidents on the workplace, Daalmans (2014) speaks about a 'bathtub'- effect in statistics. Newcomers as well as workers with new procedures or materials encounter many minor accidents ("childhood diseases"). After a brief time, the volume of incidents will decrease (people become aware of the different risks and increase their knowledge and competences). However, at a certain time, an increase of incidents is expected due to habituation, as described by Daalmans in an example considering bus drivers (Figure 1).

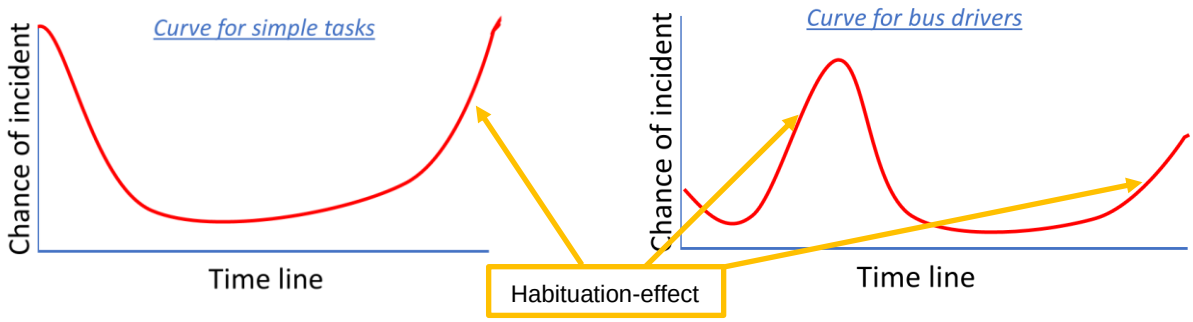


Figure 1. Examples of the habituation-process for simple and complex tasks (Daalmans, 2014).

If habituation can be seen as a basic and sub-conscious process that interfere with risk perception, some other cognitive processes, like illusions and emotions, could limit our understanding of the different risks. In this context, a too high self-overestimation of the road worker can lead to neglecting problems or risks and encourage dangerous or risky behaviours (Baumeister et al., 2003). Surprisingly, people share a realistic view on the (in)security of others whereas they develop a too optimistic view on their own risk-related activities.

On the other hand, workers can also over-respond to risk-related situations by enhancing the safety instructions and procedures. Prevention instructions and on-site mitigation measures need to be a one-to-one response to the risk. This response is strictly followed by the road worker without interference of illusions or emotions. For example, in the dark, a road worker might be tempted to add additional led lights to increase his safety perception and feeling but that can reduce the visibility of the road user and - on the contrary - increase the risk of intruding the work zone.

Workload is also an essential element to consider. If people experience a certain pressure to work faster, or to reach the deadline, this can lead to neglecting safety procedures. Two reasonings can explain this phenomenon of risk willingness in the work environment:

1. A consequence of the willingness to be a good and performant worker: most people want to perform in their job and reflect the image of competence. Working faster can be one of

the subjective norms of being 'competent'. Working faster can also have as consequence that some safety procedures are not followed. Most of the time, these neglects do not lead to negative consequences. Here is a contradiction: on the one side, workers learn that neglecting safety rules is dangerous and on the other, it provides positive consequences as the work is done with a higher productivity. This can lead to the thought that people who take more risks can achieve more success in work.

2. A consequence of the 'loss aversion': if people can avoid losing something (time, success, money, friendship, …), they are prepared to take more risks (Kahneman, 2012).

Sometimes, road workers start some activities on the road before every necessary prevention or mitigation measure is fully deployed. They do not want to lose time by waiting that all the announcement trucks are located correctly.

This phenomenon can be specifically an issue for road works as deadlines are often very sharp and governments sometimes are willing to pay more for a work to end earlier. This can lead to a more unsafe behaviour from the road works contractor and his employer.

3.1.3 Basic psychological rules in TTM

Considering the role of human factors in accidents in and around work zones and the limitations of psychological processes, some basic psychological rules can be proposed:

- **Keep the driver in mind when arranging and designing a work zone** – usually possible dangers are underestimated, drivers don't realize the impact of speed on stopping distances, get confused, have difficulties in perception at night…
- **Keep the cognitive workload low** – use text messages only when necessary, use simple signs, allow enough time for perception of signage…
- **Avoid surprises** – a driver always comes back to what he knows and what he expects.
- **Avoid confusion** – non-relevant events and misleading elements can distract the driver from the driving task and influence the interpretation of the situation, leading to accidents.

3.1.4 PIARC's 4 C's concept

PIARC (2012) proposed a 4 C's principle for safe, efficient and effective management of road work zones. They should be:

- **Conspicuous** – this implies that the driver must be physically able to see what is coming up. The work zone must be obvious, noticeable and eye-catching to draw the attention of the drivers and encourage them to act in the desired way with regard to increased attention, speed adaptation and position of vehicle.
- **Clear** – which means that all signing, guiding and other instructions through road works must be clear for drivers so they can be absolutely certain about what is required in terms of correct decisions about how to safely approach and pass the site.
- **Consistent** – which implies that drivers should encounter uniform standards, layouts and arrangements at all work zone sites of the same kind, so they are conditioned to act in a certain expected way.
- **Credible** means that the instructions are 'believable' so the drivers can rely on what they are told (e.g. the need to slow down) and that the messages they are given are a true representation of what will occur ahead.

Those principles also include aspects of the psychological issues mentioned above, as following those principles enables drivers to concentrate on the important topics when approaching and driving through a road work zone.

3.2 Implementation principles

3.2.1 Data collection

An essential part of effective safety measures is keeping track of all the incidents and accidents that happened in and around the work zones. The BRoWSER project, that finished in 2015, contained a part dedicated to data collection and storage. A database called European Road Worker Casualty (EuRoWCas) was developed. The main aim of the EuRoWCas database is to help National Road Authorities (NRAs) to take an evidence-led approach in managing road worker safety and to allow benchmarking of safety. In addition, a database provides a potential mechanism for sharing information on safe road work practices. Local implementation of EuRoWCas would provide benefit for individual NRAs but the greatest benefit would come from implementation and sharing data between NRAs across Europe (CEDR, 2015). Details about this database and its implementation can be found in the deliverable of CEDR, 2015, BRoWSER D11_1 EuRoWCas - Guidance and information for NRAs.

3.2.2 Duration and length of work zones

Undoubtedly, with increasing duration and length of work zones, the exposure increases as well, which will lead to a higher probability of accidents. This has been confirmed in the SafetyCube[1] project as well. The factor “length of the work zone” was considered as “risky”, the factor “duration of the work zone” was considered as “probably risky” by SafetyCube.

Due to economical and traffic reasons, road works are never longer than needed, but there is the organisational choice of dividing the work zone. However, replacing one long work zone by several short ones, could increase the total duration, thus causing negative effects prevailing possible positive effects because of the shorter work zones. There will always be the need for a risk assessment based on the site conditions. In any case, organisational or infrastructural measures to shorten the duration of a work zone will decrease exposure and thus improve the safety record.

3.2.3 Segregation of work zones and road users

A basic principle to prevent vehicles from intruding into work zones is to physically separate the road user from the work zone. In long-term work zones physical barriers (mostly steel or concrete), that comply with the obligations according to EN 1317, should be used whenever possible. For short term work zones this is often not feasible. However, a segregation by beacons, cones etc. is foreseen in most guidelines. Putting obstacles in place that are not “collision friendly” (like blocks of concrete) to prevent incursions should be avoided due to the possible injuries of drivers colliding with these obstacles. To enhance safety, other safety measures such as reduction of legal speed, prohibition of overtaking or – if possible – increase of lateral safety distance are reasonable.

[1] SafetyCube (Safety CaUsation, Benefits and Efficiency) was a research project funded by the European Commission under the Horizon 2020 EU Research and Innovation programme. The primary objective of the project was to develop an innovative road safety Decision Support System (DSS) that enables policy-makers and stakeholders to select and implement the most appropriate strategies, measures and cost-effective approaches to reduce casualties of all road user types and all severities in Europe and worldwide.

3.2.4 Speed control

One major problem in many work zones is the lack of compliance with legal speed limits. Speed control is necessary to reduce the risks of serious accidents and the risk of incursions into work zones. A gradual reduction of the speed limit on the approach to the work zone in many cases is reasonable to reduce the danger of rear end accidents and to harmonize the speed level. Commonly used are decrements of 20 km/h. Usually, mandatory speed limits are applied. To ensure adherence, enforcement is crucial, which can be done either by police presence, stationary speed cameras or average speed control.

3.2.5 Forgiving roadside

Space is often limited in work zones, leading to narrower lanes and a reduction of possibilities to react and recover from small mistakes. Usually, legal speed in work zones is lower than under normal circumstances. Still, devices used in work zones should be as “collision friendly” as possible. This applies especially for temporarily applied signs, lampposts, etc.

 Source: KFV	 Source: KFV
Sign behind barrier	Sign mounted on single concrete barrier – severe consequences in case of run off accidents ⇨ not obstacle free, no forgiving roadside

Figure 2. Example considering “forgiving roadside” at work zones

3.2.6 Design principles

A detailed description of practices in road work signing and equipment and an analysis of several national performance standards and guidance documents has been conducted within the BRoWSER-Project (CEDR, 2015) [Standard and guidance report, D7.1]. Various examples of road work designs of different European countries are given in the report, distinguishing between major road works, minor road works, and mobile road works on motorways and single carriageway roads, respectively. Common practices, significant differences and recommendations for a harmonisation throughout Europe were stated for these topics [Recommendations for consistency, D12.1 & D13.1]:

- Advance warning
- Transition area / vehicles
- Temporary speed limit schemes
- Lateral safety distance, lane width & delineation of the work zone

Signage installation and improvement are effective according to SafetyCube project: *“The effects of workzone measure implementations relate to road safety level improvements, with a large number of literature studies presenting findings indicating a reduction in speed and speed*

variance, and improved lane keeping. In areas that are located a large distance before the workzone environments, where no active work seems to be taking place, workzone signage seems to be counter-effective, namely reducing speed limit compliance rates, thus indicating that there are optimal and sub-optimal points for workzone measures application. The examined studies have good levels of quality, and are overall consistent in their results."

https://www.roadsafety-dss.eu/#/references?topic=COUNTERMEASURE&taxonomy=5810&kwdId=537

Design principles and highway codes mostly consider driver's needs and hardly regard safety issues from a worker's point of view. On the contrary, there are often regulations applicable to road workers, that might contradict road work zone design principles. Ideally, there is harmonisation between the relevant actors taking both aspects into consideration.

 Source: KFV	 Source: KFV
No misleading existing markings left in place, work zone markings guide drivers correctly	Misleading work zone marking – guidance into the work zone area ⇨ not clear, not credible ⇨ confusing

Figure 3. Example considering design issue marking at work zones

 Source: KFV	  Source: KFV *Comment: sometimes existing signs are damaged due to crossings (e.g. by use of screws or adhesives). There are magnetic systems available that are easy to apply, and a damage of the signs is prevented.*
Complete coverage of obsolete sign	Obsolete sign is crossed – which might be seen and recognised during daylight but hardly at night ⇨ camouflage ⇨ not conspicuous

Figure 4. Example considering design issue signing at work zones

3.2.7 Considering vulnerable road users

High speed roads have the greatest risk regarding incursions into work zones with severe accidents including road workers. In urban areas lack of provision for cyclists and pedestrians around work zones often poses a problem for these vulnerable road users.

Generally, in guidelines it is usually stated that provisions for vulnerable road users must be provided. Still, experience of the authors of this report, from their practice as Road Safety Auditors, reveals deficiencies too often in this respect. The situation even gets worse when considering the needs of disabled people.

This issue must be considered while planning the work site, during establishment and maintenance of the construction site, and during controlling of the work site – an integrated approach and the conduction of Road Safety Audit and Road Safety Inspection could improve the needs of vulnerable road users in work zones. Even if the EC Directive 2008/96/EC (EC, 2008) does not put any specific demand for RSA or RSI concerning road work zones, it is a good starting point to develop RSA and RSI procedures with respect to vulnerable road users.

In addition, awareness-raising activities should be carried out in this respect.

3.2.8 Considering work zone personnel

Working on roads in or nearby traffic is dangerous and requires a lot of skills. As mentioned above, a habituation effect can often be detected in the sensitivity of workers for the existing risks leading to a misinterpretation or less careful behaviour. Inspections of work zones, which are performed in different countries to various extents, can increase risk sensitivity, but ideally the workers should maintain a realistic estimation of possible risks themselves and adapt their behaviour accordingly.

The interviews with practitioners/experts revealed that a responsible person for safety must be nominated for every work zone (supervisor, work zone / safety coordinator). It is this person's responsibility that all required safety measures are met and that workers are aware of the risks and what to do to reduce the probability of an accident.

During the interviews with practitioners/experts and in a workshop held within the project, several topics were stated regarding skills of work zone personnel:

- barriers not correctly applied – too short, elements not connected,…
- lack of basic health and safety trainings of the employees in work zones
- workers not trained or tested, if they are able to work in strenuous work zones
- no official or regulated education for some works in some countries, education of workers only voluntarily or very short
- lack of safety awareness, e.g. inappropriate equipment, risky behaviour

Appropriate skills of personnel at work zones increase safety in all aspects, for road users and the workers themselves. Measures to enhance the skills of personnel like definition of competences in the contract, regular awareness raising within construction companies, educational measures etc. help to improve road work safety.

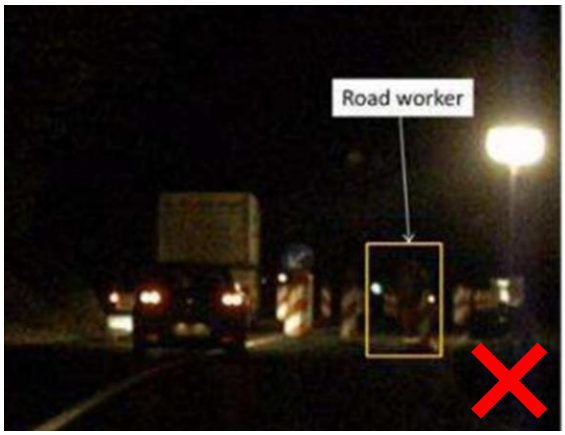
 Source: DGUV	 Source: Uroš Brumec
Appropriate clothing of workers at a work zone	Inappropriate clothing of a worker at a work zone

Figure 5. Clothing of workers at work zones.

4 Best practice measures to improve safety at work zones

This chapter gives an overview of measures and practices that are considered as enhancing safety. Further, also some interesting fresh solutions and approaches regarding measures to improve work zone safety, revealed by the interviews with the road authorities of the countries participating in this project, are presented. The establishment of Road Infrastructure Safety Management procedures requested by the EC Directive 2008/96/EC (EC, 2008) provides national road agencies with effective tools to improve safety even at road works. Safety there is just as important as at the rest of the road network.

4.1 General issues - regulation, management and qualification

4.1.1 Raising safety awareness

A prominent issue is to ensure that all parties involved in designing and operating work zones see safety as a top priority. This includes designers, employees of road authorities and road operators, construction companies, contractors and subcontractors, and the workers on the site. Measures to raise awareness among these people, stated in the interviews were:

- training courses, qualification, accreditation/certification of e.g. contractors/ subcontractors – there is a wide range of requirements between the countries; some countries have specific procedures and requirements (e.g. United Kingdom, Ireland, The Netherlands, Sweden), in other countries education of workers is not required systematically (e.g. Austria, Belgium)
- Germany: “Risk parcours” – internal educational measure for employees of road authority to raise awareness of safety aspects at work zones
- The Netherlands: specific guidelines for road workers with e-learning and approval, for very short interventions
- Slovenia: after problems with contractors, establishment of work zones (cones, chevrons, etc.) is now exclusively done by personnel from road authority/road operator to ensure that qualified people are doing the work.

As presented in chapter 3.1.2, risk-sensitivity and risk-understanding are two parameters to influence the safety attitude and behaviour of the road worker. Hence, illusions, emotions and overload can be parameters inducing unsafety. Instructions to the road worker and on-site prevention and mitigation measures need to be repeated and need to be an evidence-based response to the risk and its possible consequences. This response should be strictly followed by the road worker with limited habituation, emotions or illusions to interfere. This will allow the risk not to be under- or over-perceived by the road worker. These topics ideally should be covered in safety awareness trainings of road workers.

In the interviews, some campaigns aiming to improve the road user’s understanding of safety related issues of work zones were mentioned:

- Belgium: campaigns focussing on speeding in road work zones 2014/15
- Germany/Nordrhein-Westfalen: campaign during introduction of use of rumble strips and during introduction of cell broadcast (CB); 1-2 times/year reports in local TV about road safety related issues
- Sweden: the union of workers carried out a campaign at road works based on international example “My dad works here” a few years ago (see figure 6).

Figure 6. Example of campaign “Show consideration to my father”, Sweden.
Source: https://www.jp.se/article/varfor-star-vagbyggena-stilla-sa-lange/

Awareness raising campaigns usually aim at road users in the respective country, using the local language. In a European context, it should be a target to design the campaigns in a way that the content of a campaign is understood regardless of language.

On October 11th, 2018, a workshop was held at Vias institute in Brussels to present the interim results of the IRIS project and to receive feedback on the recommendations and current work zone safety practices. During the workshop, several attendants stated that road users seem to have difficulties in understanding signage and fail to behave accordingly. To tackle this problem, in Germany, pictures of road work zone issues were developed for education in driving schools, thus raising awareness for the significance of traffic regulations in road work zones.

4.1.2 Standardisation of design and work sequence

Work zone design is usually done based on national guidelines and regulations. These documents typically include example layouts for distinct types of work zones, covering markings, signing and infrastructural elements to be used. A detailed description of practices in road work signing and equipment and an analysis of several national performance standards and guidance documents has been conducted within the BRoWSER-Project (CEDR, 2015) (see chapter 3.2.6).

In Germany (Hessen) standard plans for work sequences have been developed by Hessen Mobil Straßen- und Verkehrsmanagement, e.g. describing in detail the procedure to establish a work zone. These plans are considered as a help for construction companies and workers on site and shall help ensuring a desired quality level during works.

https://mobil.hessen.de/verkehr/intelligenter-verkehr/baustellenshymanagement/sicherheitskonzept-f%C3%BCr-baustellen

4.1.3 General design regulations and guidelines

In the long term, design regulations and guidelines can contribute to work zone safety, and especially safety during maintenance work, as well. For example, plantings in the median strip need to be taken care of. By reducing grass or plantings near the road the need for maintenance work is reduced and so is the exposure of road workers.

Figure 7. Median strip without and with grass.
Source: KFV

Hard shoulders that are wide enough for facilities to carry out maintenance operations also contribute to the road workers' safety. The same can be achieved by breakdown bays or stopping niches near gantries that facilitate maintenance. Getting out of and in the vehicle is safer when there is a safe zone to park when carrying out activities.

4.1.4 Safety related issues in the tender

Procedures differ between countries, but generally contractors are obliged to follow national laws, rules and regulations, which usually include safety aspects. To emphasise the importance of safety, safety issues can be a part of contracting, thus making safety an assessment criterion.

Example:

In recent years, major Austrian clients tried to shift in tenders from "cheapest offer" to "best offer". ASFINAG, the Austrian road operator of the high-ranking network, had several tenders where construction companies had to illustrate planned measures to enhance safety in the work zone. Measures going further than legal standards are rewarded within a point-system, and it is estimated that up to 1-2 % of the financial results of the tender deal with additional safety measures. Quality criteria in the tender also lead to a certain amount of administration, but generally, it was mentioned that this measure increases awareness of constructors regarding the topic.

4.1.5 Work Zone Safety Examinations

For ensuring a successful work zone safety process the practitioners involved should “see the big picture”, i.e. how the various components of Work Zone Safety Examinations interrelate. To achieve this, the agency must have (ATSSA, 2013b):

- Overarching policies that clearly spell out responsibilities and competencies for individuals involved in the work zone inspection program from agency to project levels;
- A monitoring program that regularly evaluates the effectiveness of agency policies and project-level actions;
- A standardized procedure for program and project deficiency identification and follow-up;
- A process that folds feedback on performance back into the program as a whole.

The agency should develop guiding principles, procedures, and resources that form the basis upon which the program operates. Once established, these guiding principles should be updated through process reviews and self-assessments performed at a regular basis. Detailed documentation of all relevant aspects of the process, program or project being inspected is important. Documentation across all levels of inspection and review activities should be maintained.

An effective Work Zone safety process involves two basic levels of reviews:

- **Agency level review activities,** which deal mainly with process related elements over longer periods of time and involve review and response to policies and processes.
- **Project level activities,** which involve a more ‘real-time’ look at conditions specifically within the project.

The outcomes of both levels of reviews should be evaluated and feedback provided into the respective processes.

Agency level review activities include:

- **Work Zone Process Review**, guiding an agency through an assessment of the functionality and effectiveness of practices and procedures used to audit or inspect work zones. Process reviews can assess whether operational processes, within a work zone inspection program, are consistent with established standards and expectations, performing effectively and efficiently, and if the practices are adequately captured and applied within the program, or across other programs at an agency.
- **Work Zone Self-Assessment** can help road agencies to manage their work zone program. WZSA looks at the following areas: leadership and policy, project planning, project design, project construction and operation, communications, education, program evaluation.
- **Work Zone Crash Data Trend Analysis** involves analysis of aggregated work zone crashes with an emphasis on crash contributory factors and discussion of countermeasures.
- **Regional Work Zone Reviews** are a higher-level, multi-project assessment of inspection practices across the agency regions. This review may take the form of quarterly meetings of project inspectors with notes being compared as to satisfaction with or issues related to inspection processes and their outcomes.

Project level activities include:

- **Crash and Mobility Data Analysis**
- **Work Zone Road Safety Audits**
- **Work Zone Road Safety Inspections**.

Crash and Mobility Data Analysis

Crash and Mobility Data Analysis evaluates current or real-time crash events and mobility issues in an active work zone. This activity is conducted as soon as practical, following a crash event or serious mobility issue within the project limits. In order to assess mobility issues, traffic volumes should be measured prior to the start of the road works and compared to the road capacity during the different phases of the road works. It might be necessary to take additional measures to spread traffic in the surrounding road network. Information on crash contributory factors or serious mobility deficiency should result in immediate actions to reduce the chances of a recurrence. Sources of information on contributory factors that may have led up to the crash may be available from inspector logs, police reports, contractor reports or contractor or agency witnesses. Remediation of any situation or condition that may have contributed to the event is the responsibility of the project owner. Performing Crash and Mobility Data Analysis should be standard operating procedure for national road agencies. In case of large projects, aggregation and analysis of project related incidents may lead to identification of thematic problems. Findings from crash data analysis can help understanding the types and contributory factors of work zone crashes and emphasis areas for improvement can be identified.

Work Zone Road Safety Audit

Work Zone Road Safety Audit (WZRSA) is a formal safety performance evaluation performed at any stage of a planned work zone by an independent, multidisciplinary team, and considers methods of improving safety in a work zone. The difference between an RSA and a WZRSA is in the tailored RSA approach incorporated into the unique challenges of work zones. A WZRSA assesses project's temporary elements that will eventually be removed once the active work zone phase is completed. Hence, a WZRSA team should focus on work zone safety, design and operations; it should not focus on permanent geometric design elements. WZRSAs can be done during all project phases – from planning through an active work zone. Due to the temporary nature of work zones, the WZRSA team must record its findings and submit recommendations to the road owner in a timely fashion (ATSSA, 2013a). The individual phases of WZRSA, with their own particularities are shown in Figure 8.

The Work Zone RSA Guidebook (ATSSA, 2013a) provides WZRSA prompt lists for Planning Phase, Preliminary Design Phase, Final Design Phase and Active Work Zone and a WZRSA Report Template, as well as case study examples Printable and electronic prompt lists are downloadable from the National Work Zone Safety Information Clearinghouse website (www.workzonesafety.org). The Florida Department of Transportation (FDOT) has created an RSA tracking database, which can be accessed at http://safety.fhwa.dot.gov/rsa/sampledb/.

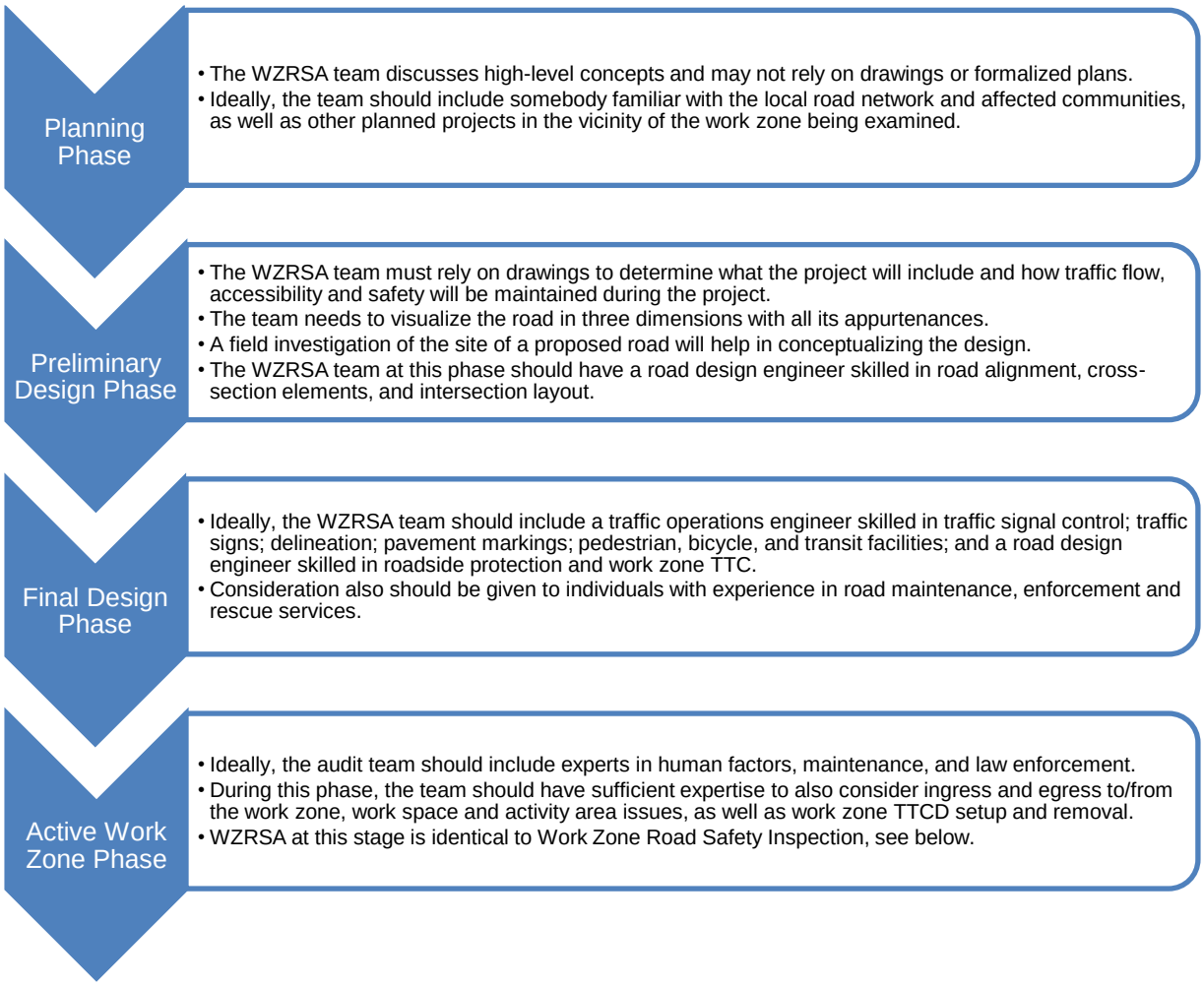


Figure 8. The individual phases of WZRSA.

Work Zone Road Safety Inspection

Work Zone Road Safety Inspection (WZRSI) is a formal review of temporary traffic control devices (TTCD) and safety/mobility strategies deployed according to an approved plan, standards and specifications in active work zones. Work zone inspections are done during the active work zone phase. Compliance and deficiencies are documented formally, using a work zone inspection sheet. Work zone inspection sheets can vary in complexity and categories, but typically identify criteria deemed most critical to the work zone (e.g. signing quality/location, whether the work zone set-up matches design plans, presence of flaggers, safety/mobility concerns, etc.) (ATSSA, 2013a).

WZRSI should be applied at all long-term road works. Based on Elvik (2006), the following guidelines for good WZRSI practice are of importance:

1. Inspections should be standardised and designed to ensure that all elements included are covered and assessed in an objective manner.
2. The elements included in WZRSIs should stand as risk factors for accidents or injuries.
3. Check lists for WZRSIs should include the following core of important elements:
   a. Traffic signs, their need, their quality and whether they are correctly placed or legible in the dark.
   b. Road markings, their quality, in particular whether they are consistent with traffic signs or are visible.

   c. The quality of the road surface, in particular with respect to friction (macro and micro-texture) and evenness.
   d. The adequacy of sight distances and the absence of permanent or temporary obstacles that prevent timely observation of the road or other road users.
   e. The presence of roadside traffic hazards.
   f. Aspects of traffic operation, in particular if vehicle speeds are adequate to local conditions at road work zones.
4. For each element included in an inspection, a standardised assessment should be made by applying the following categories:
   a. The item represents a traffic hazard that should be treated immediately. A specific treatment should be proposed.
   b. The item is not in a perfectly good condition or deviates slightly from current standards, but no short-term action is needed. Further observations are recommended.
   c. The item is in good condition and in accordance with current standards.
5. WZRSI should state the findings and propose safety measures in a standardised report.
6. There should be a follow-up of WZRSI, to check if the proposed countermeasures have been properly implemented.

WZRSI should be performed in various selected periods of time, so that the most relevant traffic situations are covered: day and night, dawn or dusk in East-West aligned roads; winter and summer. To guarantee that every WZRSI is free of subjective elements, irrespective of the performing inspecting team, standardised report forms should be used. To achieve objectivity, standardised text for most common hazards describing a number of typical frequent situations should be used. A standardised report form has the advantage of being easy to read and allowing comparing different reports. The content of the checklists should reflect the prevailing relevant types of hazards that may be encountered. However, 'Fresh Eyes' are very important in the make-up of the inspection team (Nadler et al., 2011).

Auditors should be formally qualified for their job. They should meet on a regular basis, to exchange experiences and to ensure a uniform application of safety principles in the inspections.

These guidelines are general, and each country should define its own national regulatory and administrative framework, as well as procedures for WZRSI. Legal competences of road operators and of the ordering entity should be clearly specified. To ensure that there is a diversity of skills within the inspection team, it should have at least two inspectors - in all but the simplest WZRSI.

Various WZRSI checklists can be found and are in use worldwide (see Annex 1). However, it seems reasonable that a simple but effective check list like e.g. provided by PIARC is used during a work zone inspection.

Various software tools using digital video equipment have been developed to improve the quality and efficiency of the inspections of the road infrastructure. These tools can be employed with advantage for WZRSIs. Examples of such tools are:

- **EVES (Electronic Safety Recording System)** developed in Austria to assist in carrying out road safety inspections (Nadler et al., 2011).
- **UBIPIX** - an electronic tool for TTM inspections but also for RSI in Ireland. (https://nra.ubipix.com/index.php?action=faq).
- **Vidkon** – a Norwegian digital video equipment for RSI (Cardoso et al., 2005).

4.2 Establishment of work zones

The establishment of work zones is a phase that poses many risks – devices have to be put in place, the situation for the drivers changes, workers are even more exposed to oncoming traffic than under regular work zone conditions. Reducing the exposure of the workers improves their safety situation.

4.2.1 Stopping all traffic during establishment of work zones

If a complete stop of traffic is not feasible, a reduced flow or slowing down traffic might be considered. A possible means is a rolling roadblock, which closes all lanes of traffic by using pacing vehicles; thus, a gap is created so that construction activities can be performed. Rolling roadblocks are used in the United Kingdom and the United States.

https://www.workzonesafety.org/training-resources/fhwa_wz_grant/atssa_rolling_roadblocks/

4.2.2 Protection measures during establishment of work zones

If an all-stop-procedure is not feasible, protection measures for workers must be implemented during establishment of work zones. Possible measures according to the interviews are

- temporary speed reduction and warning of road users that workers are present installing temporary traffic management (TTM) (United Kingdom)
- establishment of TTM under the protection of Truck Mounted Attenuators (TMAs) (United Kingdom) / Impact Protection Vehicles (IPV) (United Kingdom / Ireland, dual carriageway roads)
- rolling road blocks (see above, United Kingdom)
- use of permanent infrastructure (signing gantries) and pre-identified fixed taper positions (United Kingdom)
- providing platforms on trucks for workers for depositing and removing cones making it unnecessary for them to walk on the road (Austria)

4.2.3 Automation

A possibility to reduce the exposure of workers to oncoming traffic is the use of automated vehicles for works in work zones or the automation of deployment and dismantling of devices used in work zones. Development and testing of devices has long been going on (see e.g. Lee et al., 2004).

In recent years, several attempts were made in Europe with new developed devices, with mixed results, as also revealed in the interviews:

- **Germany** is testing automated vehicles for work zones on highways.
- **Ireland**: tests of cone dropping with remote control; the system did not suite the Irish scenario, so it is not used anymore in Ireland.
- **Sweden**: Painting of road markings done by an automated vehicle.
- **United Kingdom** is looking into the possibilities of remotely controlled vehicles with TMAs.

Figure 9. Example of Automated Cone Machine.
Source: http://www.worldhighways.com/categories/road-markings-barriers-workzone-protection/features/safer-cone-collection-with-x-cone-among-the-latest-safety-innovations/

4.3 Informing, warning & guiding of road users

4.3.1 Mobile gantry cranes

Use of mobile gantry cranes with variable message signs improve visibility of the road signs. They can be deployed from the hard shoulder, but possible space constraints must be considered. Mobile gantry cranes, being a roadside obstacle themselves should be put behind a barrier. This, however, would limit their possible application (see e.g. Figure 10 – if the mobile gantry crane was put behind the barrier, the signing above the lanes would not be possible). In this respect, the mounting of crash cushions on the mobile gantry cranes is highly recommended if they are not placed behind a barrier.

Figure 10. Example of a Mobile Gantry Crane.
Source: Traffic Service Nederland, https://tsned.nl/producten/mrs/

4.3.2 Intelligent Transport Systems

Modern technology can be used to improve the information for drivers when approaching a work zone / work zone vehicles or when driving within the work zone. Intelligent Transport Systems (ITS) and variable message signs (VMS) are used more frequently on motorways. Existing gantries should be used as much as possible for information on road works as well, in addition to the manually installed temporary signs. Some examples were stated in the interviews:

- **Germany**: lorry drivers (long distance drivers) receive information on work zones via cell broadcast (CB) in different languages – traffic signs and barriers of work zones are equipped with signals.
- **The Netherlands**: Maintenance and intervention vehicles are equipped with a button to transmit locations. Drivers receive notification of this intervention on their navigation system instantly.
- **United Kingdom**: Due to using the readings of the inductive loops in the pavement, it is possible to calculate the optimal speed limit for a long stretch of road ahead of the congestion. The optimal speed limit is displayed on VMS and creates a traffic flow that is equal to the capacity in the congested stretch of road. This avoids leading drivers to a standstill.

Road works usually cause a capacity reduction and increased travel times. An indication of deviation and estimated travel times is appreciated information for road users, and it can be provided with the help of sensors and variable message signs. Travel times can be calculated accurately using Google Maps and be displayed on VMS (see e.g. Mikulski, 2017). In case a stretch of road is closed for road works, a deviation is necessary. This can also be displayed on VMS, in combination with the calculated travel time.

Figure 11. Example for indication of estimated travel time.
Source: http://www.superiortelegram.com/business/transportation/2322021-construction-set-begin-interstate-35-digital-signs-display-travel

4.3.3 End-of-queue warning systems / congestion warning

If queues are anticipated to occur during some portion of the work zone area, e.g. on roads with a high traffic volume - in addition to fixed, existing gantries and ITS devices - portable real-time end-of-queue warning systems are an option to reduce rear-end collisions in work zones. In the United States, a system based on easily deployable radar speed sensors was investigated in Texas. The sensors and variable message signs were linked wirelessly to a central data processing unit. Depending on the measurements queue warnings were displayed. The number of sensors and message signs was adapted according to the actual situation. The system was used during night-time in combination with portable rumble strips.

Speed sensor Pre-designed portable changeable message sign

Figure 12. End-of-queue warning system
Source:https://www.workzonesafety.org/files/documents/training/courses_programs/rsa_program/RSP_Guidance_Documents_Download/RSP_EndOfQueueWarning_Guidance_Download.pdf

The use of end-of-queue warning system and portable rumble strips reduced collisions at interstate work zones and the crashes that occurred were less severe than without the measures (Ullman et al., 2017). During queuing and congestion, the use of the countermeasures appeared to reduce accidents by 53% to 60%.

A portable congestion warning dynamic message sign indicating a congestion was tested in Sweden (Sörensen & Wiklund, 2010). The system consisted of a trigger (about 400 metres upstream from the point where the two lanes merged to one lane) activating two dynamic message signs (about 800 metres and about 1900 metres upstream before the trigger) when vehicle speeds were lower than the pre-set 50 km/h speed. The speed distribution became more homogenous during rush hours, when the system was in use. It was concluded that the most suitable distances from the sign and the trigger to the work zone have to be investigated further as well as the triggering speed level. Also, an alternative design, where the icon used for road work warning is shown together with the distance to the work zone, was proposed whenever the congestion warning is not in action.

4.3.4 Information on alternative / diversion routes

In the interviews concerns were stated regarding information on alternative routes. From safety point of view, directing traffic to an alternative route may be worse than if the traffic would stay on the main route. United Kingdom stated a preference to encourage road users to stick to main routes but provide live journey time information (see above). The risk of alternative routes should be considered before deciding whether information is provided or not.

Figure 13. Example for information on alternative / diversion routes.
Source: https://commons.wikimedia.org/wiki/File:A2_-_Signalering_dynamische_borden_Nederlandse_snelweg.jpg

In Austria a signing system with colours was used during a work zone in an intersection, to enhance the comprehensibleness of a feasible alternative route. Directions going north were coloured green, directions going south red.

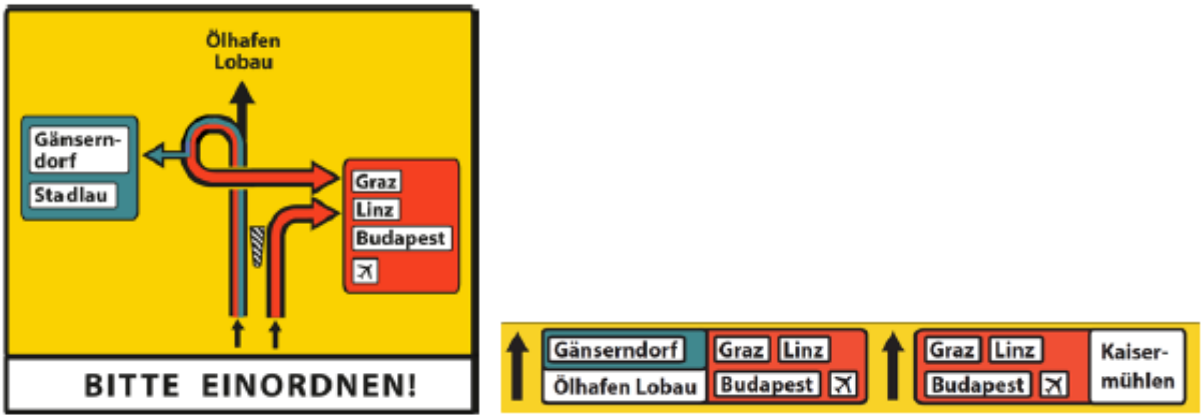


Figure 14. Example for using colours as additional information on alternative route.
Source: AIT - Austrian Institute for Technology

In case of diversion routes, an information that navigation systems might not be reliable is a possibility. However, there is no information available on how successful the measure is.

4.3.5 Safety panels

The type of safety panels used is mostly defined in national guidelines. After some preliminary studies (see e.g. Meseberg, 1997; Baier, Kemper, Meseberg, 2007), Germany introduced panels with arrows instead of stripes with satisfactory results, according to the interviews with stake holders. Arrow panels are already used regularly in other countries.

Panels are also used on vehicles as a conspicuity measure. In any case, it is recommended to use just one type of safety panel with similar colours within a work zone, otherwise the situation might be confusing / not clear for road users.

	
Similar types	Use of different types of safety panels

Figure 15. Use of safety panels within a work zone
Source: KFV

4.3.6 Portable rumble strips

Portable rumble strips can be used on various occasions. Applied on the driving lane it may be a speed reducing measure ahead of a work zone. In case of works on the hard shoulder they may be applied on the hard shoulder to “wake up” drivers and prevent them from using the hard shoulder. In some countries portable rumble strips are also used for lane closing in addition to safety panels.

There are several maintenance, effectiveness and environmental issues (e.g. noise) affected by this measure. United Kingdom stated concerns about safety of the portable rumble strips and legal problems (lack of legislation). In other European countries like e.g. Austria, Germany and Slovenia portable rumble strips are covered by the work zone guidelines.

Figure 1516. Portable rumble strips on hard shoulder.
Source: www.maibach.com

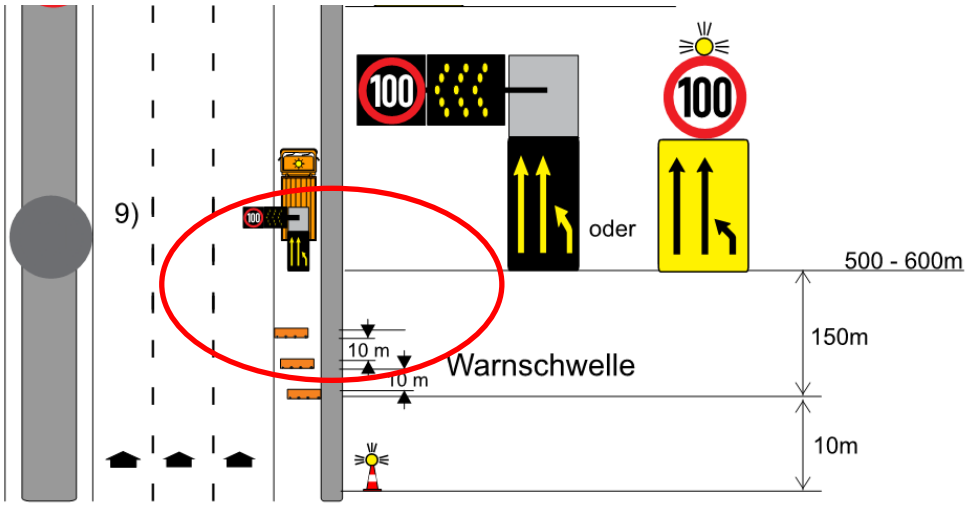


Figure 16. Principles of deploying portable rumble strips on hard shoulder.
Source: FSV (2012), RVS 05.05.42, Road Work Zone Traffic Control, Roads with Separate Directional Carriageways.

However, there is a risk to the road worker who has to put the rumble strips in place. To limit this risk, safety measures during deployment are needed. Truck mounted rumble strip handling machines, where deployment, realignment and retrieval of rumble strips are operated from the vehicle are available, in Austria, ASFINAG is testing these devices.

4.4 Speed management & enforcement

4.4.1 Temporary or variable speed limits

The interviews with stakeholders revealed that temporary speed limits at work zones are sometimes used in Sweden and in the United Kingdom. This measure only can be applied if local circumstances are in favour of the measure. In many cases temporary speed limits are applied for road user safety and need to remain in place whether workers are present or not. Otherwise, when the work shift is over and thus the risk of accidents with workers does not apply and road users' safety does not motivate keeping the lower limit, temporary speed limits or advisory speed signs should be covered.

Figure 18. Covering restrictions when work shift is over.
Source: https://www.informatiebord.nl/p/863/afzetmaterialen-werk-in-uitvoering/diverse-afzetmaterialen/afdekhoes-verkeersbord-800x1050-polypr-4-ringen-logo-1-kleur-100-stuks/

Variable speed limit signs, equipped with sensors to monitor the traffic flow could also be used to adjust local speed limits according to oncoming traffic. This approach is already used in the United States. An accurate record of when which regulatory speed limit was applied is essential for enforcement reasons and for evaluation of the safety effects of the measure.

Figure 19. Variable speed limit sign at a work zone.
Source: https://www.sierzega.com/de-de/ueber-uns/referenz

4.4.2 Dynamic speed display signs

Dynamic speed display signs measure the speed of approaching vehicles and show the actual speed on a digital display. The information can be combined with pictures like emoticons ("smiley" etc.) or verbal messages such as "Thank you" or "Slow down". Emoticons have the advantage that they are commonly understood, and no language knowledge is necessary. According to the SafetyCube project, Dynamic speed display signs (DSDSs) have favourable effects on speeds and on the number of crashes[2].

Figure 20. Dynamic speed display signs.
Source: https://www.streetsmartrental.com/products/radar-speed-trailers-rental.html/

Combining the information on driving speed with pictures or messages is often used on local roads or in urban areas like school zones, but it may be a possible measure to improve compliance with speed limits at work zones as well. Again, the devices should be put behind barriers or be collision friendly.

[2] https://www.roadsafety-dss.eu/assets/data/pdf/synopses/Dynamic_Speed_Display_Signs_26072017.pdf

4.4.3 Average speed control, speed cameras

Enforcement of speed limits generally has a positive effect on traffic safety. As concluded in the SafetyCube project, *"there is ample evidence that both section control* [i.e. average speed control] *and fixed speed cameras improve road safety."*[3] It has to be assumed that this is true also for work zones, though there are no reliable studies yet available considering this situation.

Average speed control at work zones is already used in the United Kingdom, Flanders and in Austria. Slovenia is preparing the use of average speed control. In the interviews with Austrian experts it was stated, that the use of average speed control leads to a homogenisation of traffic flow, thus enhancing safety within the work zones.

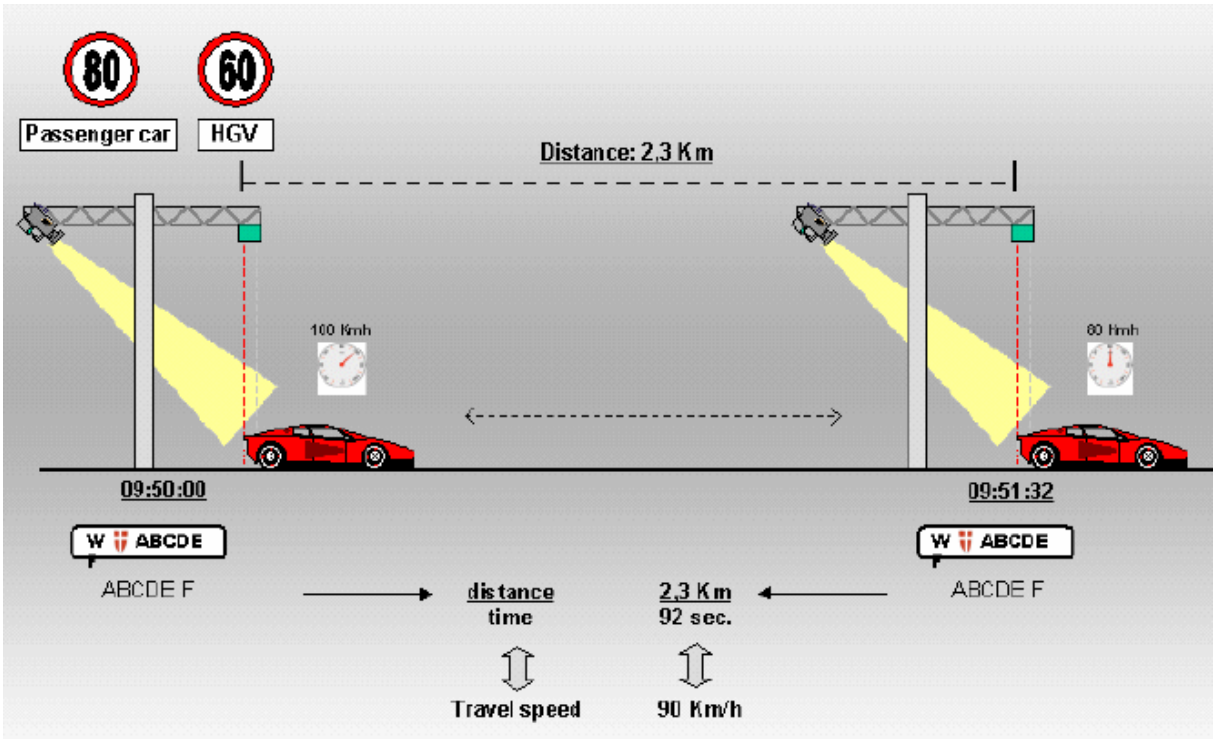


Figure 21. Scheme of average speed control.
Source: Stefan (2006)

Other enforcement methods like fixed point speed control or mobile enforcement by the police are done throughout the countries. These measures are reasonable especially in or before crucial zones like transition zones, lane shifts etc.

[3] https://www.roadsafety-dss.eu/assets/data/pdf/synopses/Installation_of_section_control_speed_cameras_23102017.pdf

4.5 Protection & lighting

4.5.1 Vehicle restraint systems

The best way to reduce incursions into work zones is a physical barrier (steel, concrete) between work zone and the traffic. Generally, when vehicle restraint systems are used, they should comply with the obligations according to EN 1317. As vehicle restraint systems are tested according to EN 1317, products are appropriate for defined speed levels and vehicles. Thus, sustaining the planned speed level is important, as the chosen system may not be suitable for impacts of heavier vehicles or vehicles driving with a higher speed than planned. In deciding upon the vehicle restraint system, aspects like required lateral safety zone, access (e.g. emergency access), road alignment or percentage of heavy goods vehicles should be considered. Another important topic is that vehicle restraint systems must be put in place according to the system's needs (e.g. length, connection of elements). This requires knowledge of the workers on-site, which must be ensured by the construction companies – and may well be a part of the contract in defining competences of the personnel.

In areas with limited space / road width small temporary vehicle restraint systems can be used. There are systems available that are tested according to EN 1317.

Figure 22. Small temporary vehicle restraint systems.
Source: KFV

Water or sand-filled vehicle restraint systems should also fulfil the criteria of EN 1317. The ballast, such as water or sand, should be as required on installation.

Figure 23. Water-filled portable vehicle restraint systems.
Source: www.jtitraffic.com

Sometimes the use of quick moveable barriers might make sense, e.g. when traffic density in the driving directions differ significantly in different times of the day. In Vienna, a quick moveable barrier was used successfully during a rehabilitation of a tunnel. In daytime, when traffic density was high, two lanes were provided for traffic. In night-time only one lane was open for traffic, thus providing more space for the work zone at night, which lead to a significant reduction of overall time needed to complete the works.

Figure 24. Quick moveable barrier and vehicle for application/moving of barriers.
Source: KFV

In the United States a different kind of mobile barrier system has been developed. It is a rigid wall trailer that can be used for protection of smaller work zones, e.g. at inspection points or small-scale repairs. According to the producer, the system is FHWA NCHRP 350 and MASH approved.

Figure 25. Work behind mobile barrier (left) and crash test of system (right)
Source: www.mobilebarriers.com

In the United Kingdom, complete closures of entrances into work zones are in use, partly also in combination with use of electronic gates and video detection.

Figure 26. Automatic gate to control access to the airlock.
Source: Highway Safety Hub http://www.highwayssafetyhub.com/roadworks-vehicle-incursions-2018.html

4.5.2 Equipment of truck mounted attenuators to measure impact

Truck Mounted Attenuators (TMAs) can be equipped with a sensor to measure the impact in case of a collision. This information is used to calculate the optimal brake force of the truck holding the shock absorber to minimize impact severity. In Ireland and in the United Kingdom this measure is specified within the standards.

4.5.3 Illumination of critical zones

Definition of luminance level (e.g. min. 0.7 cd/m²) and illumination of critical zones of the work zone (e.g. in areas of necessary lane shifting) to enhance the sight conditions at these areas.

Figure 27. Illumination of critical zones.
Source: KFV

Example:
At work zones with a duration of more than two weeks, according to Austrian guidelines, work zone lane shifts from one direction of a motorway to another must be equipped with class C4 street lighting in accordance with EN 13201-2 in unlit surroundings, including at least 50 m before and at least 10 m after this area. An adaptation area is not necessary in these cases. In illuminated environments this area must be equipped with street lighting in accordance with EN 13201-2 in class C2. An adaptation zone of 60 m must be provided in case of a speed limit 60 km/h, and of 90 m at 80 km/h except in particular cases.

4.5.4 LEDs, flashing lights

The use of running lights (sequential flashing) is implemented in most guidelines.

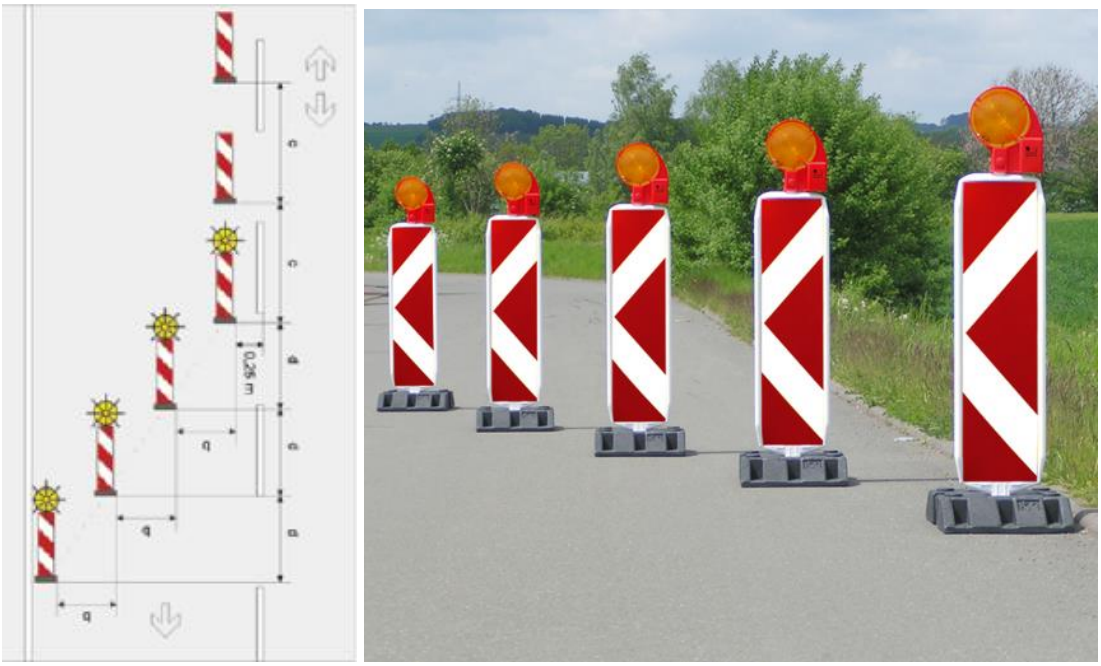


Figure 28. Running lights;
Source: BRoWSER-Project, CEDR, 2015 (left), www.rosa-moser.at (right)

Nowadays, mostly LED-lighting is used. They are reliable and need less energy, thus the need for changing batteries is lower. LEDs are used on TMAs, VMS, on vehicles and as hazard lamps. A different brightness level at day and night is desirable, as too bright lights can cause temporary blindness.

Figure 29. TMA, equipped with crash cushion and various LEDs (beacon bars, work lights, strobes). Source: www.roadsafety.co.uk

4.5.5 Incursion detection

To detect incursion into a work zone, various types of detection can be used, such as pneumatic tubes, infrared wireless technology or GPS based systems (see e.g. Wang et.al, 2013; Highway Resource Solutions, 2018). Depending on the system, an alarm is given when a vehicle enters the safety zone or if some equipment of the work zone (e.g. cone, barrier) is moved or destroyed. Incursion detection systems are sometimes used in the United Kingdom. However, Wang et al. (2013) in a national survey in the United States found that the application and effectiveness of Intrusion Alert Systems (IAS) are limited. The survey showed that 44 % of states with experience in these systems commented that this device was ineffective. The time for installing and removing the units was too long and the alarm sound was not loud enough at noisy work zones. Also, false alarms and maintenance issues contributed to avoiding using these devices. The application of this device at short-term work zones was not recommended until the product is improved. Similar experiences were reported from Ireland in the interviews. The use of an incursion detection system has been tested in Ireland – providing an alarm when a vehicle enters the safety zone. According to information gathered in interviews the system did not work on mobile equipment and therefore was not suitable for many Irish work zones.

4.6 Other measures

4.6.1 Information on presence of road workers

Another ITS solution is to deploy transponders on road workers and receivers on a road side screen, so when a road worker is close to traffic the screen lights up, informing drivers that there are road workers nearby. Whether the system improves safety is unclear.

4.6.2 Temporary bridge

In Austria, a temporary bridge is used regularly on roads with a high traffic volume (“fly over”). Underneath the temporary bridge smaller rehabilitation works, especially on existing bridges (expansion joints), can be done.

Figure 30. Temporary bridge (fly over).
Source: https://www.wien.gv.at/verkehr/brueckenbau/baustellen/flyall.html

4.6.3 Anti-dazzle measures, noise protection

Anti-dazzle measures may make sense in some cases if there is a problem with traffic in opposite direction (problems with blinding due to traffic lights) or to prevent distraction.

Figure 31. Anti-dazzle screens.
Source: www.maibach.com

Another possible measure is to attach noise barriers at road restraint systems. The noise barriers reduce noise for the workers, thus creating a benefit for them, and reduce distractions for the drivers passing by because of the blocked view. Crash tested systems are available and should be used in that case.

5 Recommendations

Based on the findings from the literature review, the interviews with practitioners and the discussions during the project with stakeholders, the following recommendations are made:

Contracting

- **The tender call** should request the contractor to propose procedures for regular checks (e.g. driving through the work zone every two hours to verify the integrity of the infrastructure and signalisation).
- **Shift from "cheapest offer" to "best offer"**, wherein safety, as a broad topic, is an integral part of the offer.
- **The contract** should document procedures for regular checks. The contract also should specify the duties of the contractor, most importantly:
- responsibility for the work to be carried out according to the Traffic Management Plan,
- to produce a Health and Safety Plan with defined measures,
- to appoint a work zone coordinator / a foreman on the site,
- to look to that road workers make daily controls in the course of their work,
- after the work is completed, to check if everything is restored "back to normal".
- **Reduce time stress** – when setting deadlines attention should be put on the fact that time stress may drive workers to start activities on the road before every necessary prevention or mitigation measure is fully deployed since they do not want to lose time by waiting until everything is located correctly.
- **The contractor's documentation of its performance** concerning the prescribed daily controls of the work zone should be controlled.

Management and education

- **Collect data** on all incidents and accidents in work zones. The EuRoWCas database was developed specifically for this purpose. National Road Agencies should be encouraged to use the EuRoWCas data format to report work zone incidents.
- **Improve skills and knowledge of workers** – special skills for working on roads are necessary, regarding application of barriers, safety awareness, appropriate equipment and also health and safety training.
- **Include** behaviour and signalisation related to **work zones in driving education.**

Implementation principles

- **Consider basic psychological rules** – keep the driver in mind when arranging and designing a work zone, keep the cognitive workload low, avoid surprises; consider the 4C's concept of PIARC – keep the work zone conspicuous, clear, consistent and credible.
- **Use symbols, images, pictograms** – to make it clear and understandable for everyone throughout Europe (and harmonise these signs all over Europe…).
- **Keep adaptation needs of the eye in mind** – illumination of critical zones and use of LEDs can improve safety, but glare effects should be prevented. Regulations regarding light intensity must be considered.
- **Keep the signing clear** – enough and early enough information, but only the information necessary; guide the drivers through the work zone.
- **Reduce speeding** – enforcement, average speed control, appropriate speed levels at different times to enhance the acceptance, providing information on current driving speed.
- **Use collision friendly devices** – whenever new devices are used, they should not be obstacles themselves.
- **Use vehicle restraint systems** – whenever possible, keeping in mind EN 1317.

Work zone safety examinations

- **Formal work zone safety examinations**, so called Work Zone Process Reviews, can contribute to achieving long term improvements in road safety work. A Work Zone Process Review is a periodic evaluation of work zone policies, processes, and impacts that systematically monitors the process of managing the safety impacts of work zones.
- **Good practice guidelines of Work Zone Road Safety Audits and Inspections** exist internationally, however, these guidelines are general, and each country should define its own national regulatory and administrative framework, as well as establish procedures for formal WZRSA and WZRSI.
- **The establishment of a European "Work Zone Safety Information website"** (an equivalent to the US site: www.workzonesafety.org) is recommended.
- **Work Zone Road Safety Inspection forms and check lists** are available on a number of internet sites (see Annex I).
- **Inspections** should be made not only at the beginning of the work, but also later, since experience shows that safety arrangements may deteriorate over time.
- **On-site inspections** can be facilitated; the quality and efficiency of the inspections can be improved and the exposure of the inspectors to traffic hazards can be reduced, by using software tools available on the market.
- If **deviations from the road work design** are detected, notifications, instructions and warnings can be issued and targets to eliminate deviations can be set. It seems that a good relationship with the contractor and "good spirit" allows that any deviations are solved promptly.
- **Maintain the integrity and independence of the Inspectors** – if not they might become reluctant to issue fines, to avoid making "enemies" among their possible future employers.

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Annex 1 Links to examples of Work Zone Safety Examinations and Inspection forms

Central Federal Lands Highway Division: work-zone-checklist.pdf
https://flh.fhwa.dot.gov/resources/design/forms/cfl/

Dallas Area Road Construction Work Zone Task Force
http://www.workzonesafety.org/files/documents/database_documents/WZ_Checklist.pdf

Missouri DOT: Work Zone Inspection Form
https://www.modot.org/work-zone-policies-and-tools

New York State DOT Inspection form
http://www.workzonesafety.org/files/documents/database_documents/nyform.pdf

Temporary Safety Measures Inspection - TRANSPORT INFRASTRUCTURE IRELAND (TII):
https://www.tiipublications.ie/library/CC-STY-04002-03.pdf

The National Work Zone Safety Information Clearinghouse website
http://www.workzonesafety.org

The Federal Highway Administration (FHWA) RSA website:
http://safety.fhwa.dot.gov/rsa/

The PIARC report: Improvements in safe working on roads, 2012R29EN, contains checklists and related instructions:
https://www.piarc.org/en/order-library/18274-en-Improvements%20in%20safe%20working%20on%20roads.htm

Work Zone Inspections Guidelines - The Federal Highway Administration (FHWA)
https://www.workzonesafety.org/files/documents/training/fhwa_wz_grant/atssa_wz_inspections.pdf

Work zone process review toolbox (The Federal Highway Administration - FHWA):
http://www.ops.fhwa.dot.gov/wz/prtoolbox/pr_toolbox.htm.

Work Zone Self-Assessment best practices (The Federal Highway Administration - FHWA):
http://www.ops.fhwa.dot.gov/wz/decision_support/self-assess.htm