# Guidance document on temporary traffic management

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# Call Safety

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IRIS Incursion Reduction to Increase Safety in road work zones.

## WP 2 Developing guidelines and recommendations

## Deliverable 2.1
## Guidance document on temporary traffic management

Deliverable No 2.1

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**Partners**

KFV - Kuratorium für Verkehrssicherheit, Austria

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Vias institute, Belgium

# CEDR Call 2016: Safety

## Incursion Reduction to Increase Safety in road work zones.

## WP 2 Developing guidelines and recommendations

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### Guidance document on temporary traffic management

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## Abbreviations

| | |
|---|---|
| CEDR | Conference of European Directors of Roads |
| DSDS | Dynamic Speed Display Signs |
| FHWA | Federal Highway Administration (USA) |
| 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 |
| TMA | Truck Mounted Attenuator |
| TTM | Temporary Traffic Management |
| UFOV | Useful Field of View |
| VMS | Variable Message Signs |

# 1 Introduction

To provide a safe and efficient road infrastructure maintenance is necessary and important. In many 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. Still, 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).

This report aims at providing information on principles that should be considered during planning, establishment and maintenance of work zones, and inspection works. A lot of work and research has been done on the topic already – e.g. within the CEDR-projects BRoWSER - Baselining Road Works Safety on European Roads (2015), including the EuRoWCas database, and ASAP - Appropriate Speed Saves all People (2014). An extensive literature review has been done within the project and some of the results, e.g. of previous CEDR-projects, are included in IRIS. However, not all findings of recent studies are mentioned, as the goal was to keep the report short and recommendations concise.

The report builds on literature reviews, interviews with practitioners and experts in eight European countries (Austria, Belgium, the Netherlands, Germany, Ireland, Slovenia, Sweden, and United Kingdom), and discussions with stakeholders.

The report corresponds to the current situation. It does not cover probable future problems like the big topic 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 in possible measures to improve work zone safety.

Finally, the topic is not only covered from road user's point of view. Safety at work zones includes aspects of work safety, thus some issues of road worker's safety, human factors and recommendations for educational measures are also part of the report.

# 2 Basic principles

## *2.1 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 didn't 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 the 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**.

## 2.2 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 (Figure 1).

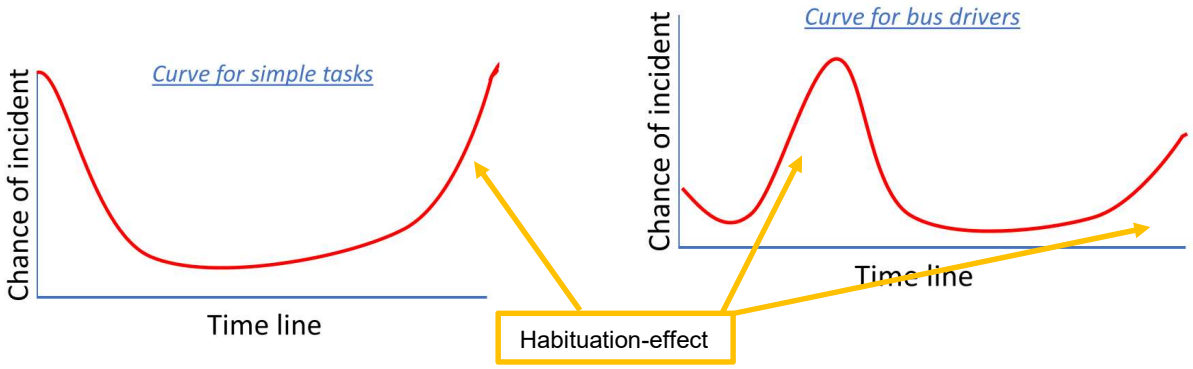



Figure 1: Examples of the habituation-process for simple and complex tasks (Daalmans, 2014).

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 don't lead to negative consequences. Here's 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 don't 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 willing to pay more for a work to end earlier. This can lead to a more unsafe behaviour from road worker and his employer.

## *2.3 Basic psychological rules in Temporary Traffic Management*

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:

1) **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…
2) **Keep the cognitive workload low** – use text messages only when necessary, use simple signs, allow enough time for perception of signage…
3) **Avoid surprises** – a driver always comes back to what he knows and what he expects
4) **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

## *2.4 PIARC's 4 C's concept*

The World Road Association PIARC proposed a 4 C's principle for safe, efficient and effective management of road work zones (PIARC, 2012): 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 means that all signing, guiding and other instructions through road works must be clear for drivers so they can be certain about what is required in terms of correct decisions about how to safely approach and pass the site.
- Consistent 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 Principles of safe work zones

## 3.1 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 risk factor “length of the work zone” was considered as “risky”, the risk factor “duration of the work zone” was considered as “probably risky” within 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 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.

## 3.3 Forgiving roadside

As stated above, 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.

The pictures below show some examples considering the topic “forgiving roadside”.

[1] SafetyCube (Safety CaUsation, Benefits and Efficiency) was a research project funded by the European Commission under the Horizons 2020. 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.

| | |
|---|---|
|  <br>Source: KFV |  <br>Source: KFV |
| Temporary barrier with terminal (at speed limits up to 80 km/h) | Concrete barrier without terminal at the beginning – severe consequences in case of run off accidents<br>⇨ not obstacle free, no forgiving roadside |
|  <br>Source: KFV |  <br>Source: KFV |
| Sign behind barrier | Sign mounted on single concrete barrier – severe consequences in case of run off accidents<br>⇨ not obstacle free, no forgiving roadside |
|  <br>Source: KFV |  <br>Source: KFV |
| Use of passively safe post | Sign mounted on concrete element – severe consequences in case of run off accidents<br>⇨ not obstacle free, no forgiving roadside |

Figure 2: Examples considering “forgiving roadside” at work zones

## 3.4 Speed control

One major problem in many work zones is 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.

## 3.5 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 (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.

The pictures below show some examples considering design topics like signing and markings.

Source: KFV

No misleading existing markings left in place, work zone markings guide drivers correctly

Source: KFV

Misleading work zone marking – guidance into the work zone area

- ⇨ not clear, not credible
- ⇨ confusing

Source: KFV

Misleading existing marking has not been removed – guidance into the concrete barrier

- ⇨ not clear, not credible
- ⇨ confusing

Source: A. Várhelyi

Another example where existing marking is in contradiction to the traffic route in the work zone

Figure 3: Examples considering marking at work zones

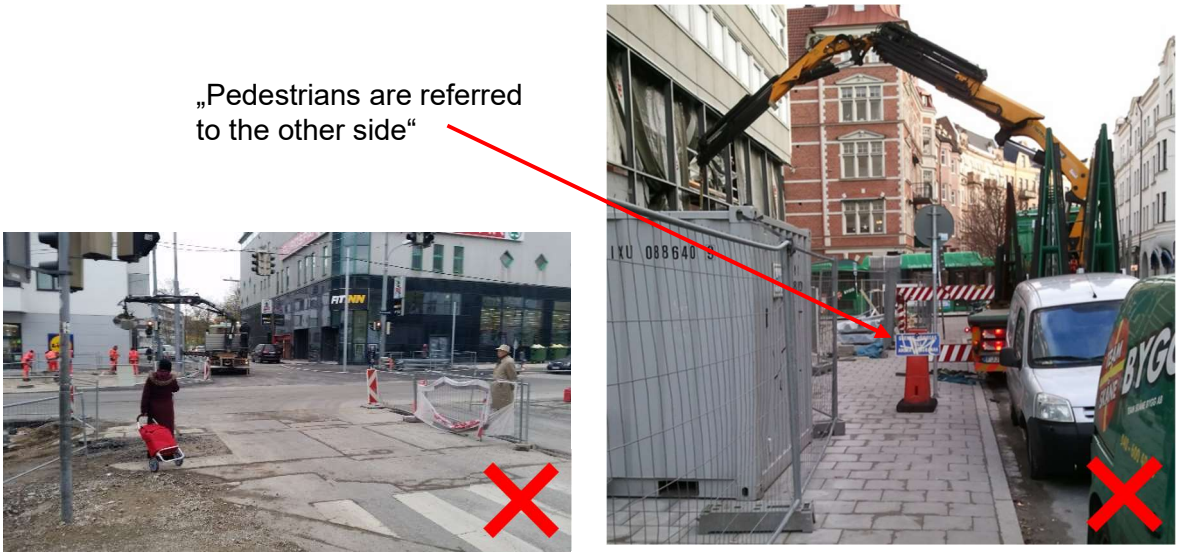
| | |
|---|---|
|  <br>Source: KFV |   <br>Source: KFV<br><br>*Comment: sometimes existing signs are damaged due to crossings (e.g. by use of screws or adhesives). There are magnetic systems available that are easy to apply, and a damage of the signs is prevented.* |
| Complete coverage of obsolete sign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

Figure 4: Obsolete signs at work zones

## 3.6 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 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, as examples on site show, a lot of times deficiencies can be detected from that point of view. The situation even gets worse when considering needs of disabled people.




Source: KFV

Source: A. Várhelyi

Figure 5: Examples of lacking provisions for pedestrians

Figure 6: Works in the course of a bicycle path

Source: H. Kröjer

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

## *3.7 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, that are performed in many 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.

According to the interviews, 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

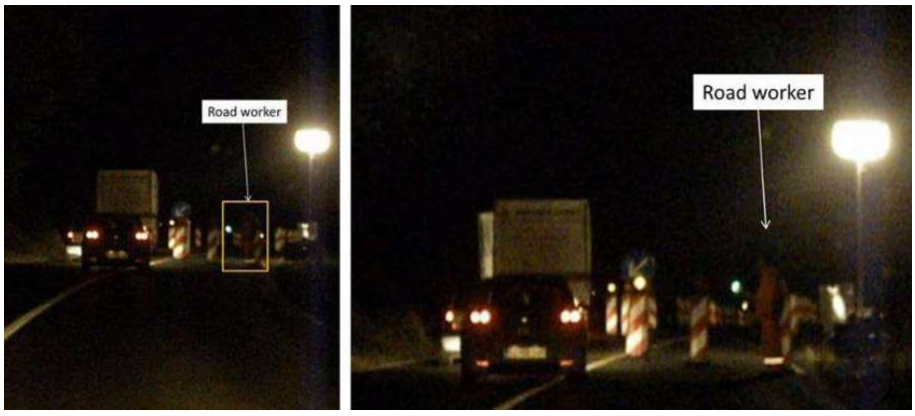



Figure 7: Inappropriate clothing of a worker at a work zone

Source: Uroš Brumec

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.

# 4 Measures to improve work zone safety

This chapter gives an overview of measures and practices that are considered as enhancing safety. Further, the interviews with the road authorities of the countries participating in this project revealed some interesting fresh solutions and approaches regarding measures to improve work zone safety are stated as well.

## *4.1 General issues - regulations, management of work zones, qualification and education*

### *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. UK, IRL, NL, S), in other countries education of workers is not required systematically (e.g. A, B)
- Netherlands: specific guideline for road workers with e-learning and approval, for very short interventions
- Germany: “Risk parcours” – internal educational measure for employees of road authority to raise awareness of safety aspects at work zones
- Slovenia: after problems with contractors, establishment of work zones (cones, chevrons, etc.) is now exclusively done by people from road authority/road operator to ensure that qualified people are doing the work

According to chapter 2.2 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 stated:

- 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 also Dutch example of “My dad works here” in Figure 8);

- Germany/Nordrhein-Westfalen: campaign during introduction of use of rumble strips and during introduction of CB radio; 1-2 times/year reports in local TV about road safety related issues;
- Belgium: campaigns focussing on speeding in road work zones 2014/15


Figure 8: Example of campaign “My father works here”, Netherlands

Source: https://www.omroepwest.nl/nieuws/2515762/Verkeersbord-voor-hardwerkende-wegwerkers-Mijn-vader-werkt-hier

During a workshop that was held within the project 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 (2015) (see chapter 3.5).

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 Road Safety Audits and Road Safety Inspections

Work Zone Road Safety Audits, i.e. formal safety performance evaluations performed at any stage of a planned work zone by an independent, multidisciplinary team, and formal Work Zone Road Safety Inspections, reviewing temporary traffic control devices, safety/mobility strategies, standards and specifications in an active work zone contribute to increase safety at work zones.

Site inspections can be conducted by the contractor, road authorities, police, external experts (road safety auditors) or work safety inspectors, respectively.

Detailed information on this topic is provided in the IRIS-report “Tools for Road Safety Audits and Road Safety Inspection at Work Zones”.

### 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 safety measures they are planning to enhance safety in the work zone. Measures going further than legal standards are rewarded within a point-system, it is estimated that this is up to 1-2 % of the financial results of the tender. Quality criteria in the tender also lead to a certain amount of administration, but generally it was mentioned that this measure lead to a positive development considering awareness of constructors regarding the topic.*

### 4.1.5 General road layout – cross section, plantings

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.

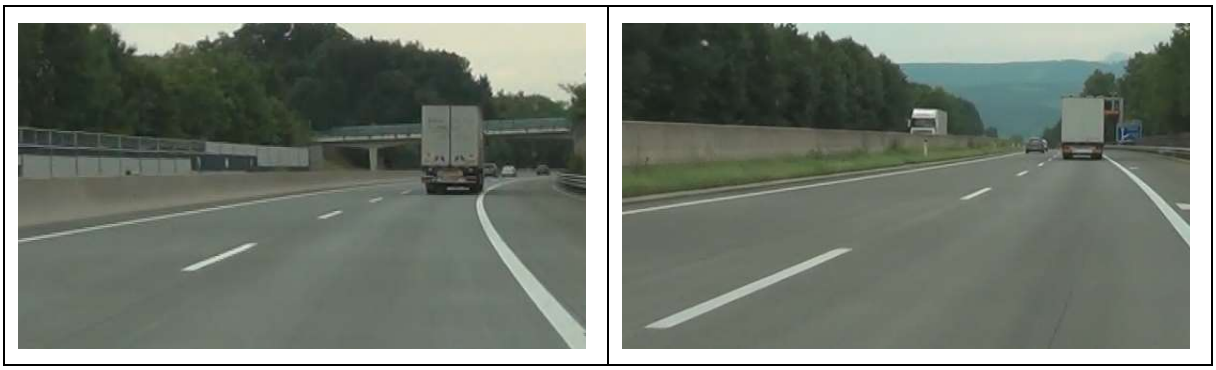


Figure 9: Median strip without and with grass

Source: KFV

Hard shoulders that have enough width for facilities to carry out maintenance operations also contribute to safety of road workers. This can also be achieved by breakdown stations 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.

## 4.2 Establishment of work zones

The establishment of work zones is a phase that poses many risks – devices must 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

Stopping all traffic during deployment of work zone signs or work zone devices completely isolates workers from traffic. Of course, due to operational reasons this is often not possible, the measure may be limited to the lower network.

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 UK and in the USA.

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) (UK)

- establishment of TTM under the protection of Truck Mounted Attenuators (TMAs) / Impact Protection Vehicles (IPV) (UK / IRL, dual carriageway roads)
- rolling road blocks (see above, UK)
- use of permanent infrastructure (signing gantries) and pre-identified fixed taper positions (UK)
- providing platforms on trucks for workers for depositing and removing cones making it unnecessary for them to walk on the road (A)

### *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 stated in the interviews:

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

Figure 10: 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 Information, warning & guiding of road users*

### *4.3.1 Use of 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.

Concerns have been raised using mobile gantry cranes, as they provide better information, but being a roadside obstacle themselves they should be put behind a barrier as well. This, however, would limit possible applications (see e.g. Figure 11 – 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 11: Example of Mobile Gantry Crane

Source: Traffic Service Nederland, https://tsned.nl/producten/mrs/

### *4.3.2 Use of Intelligent Transport Systems*

Intelligent Transport Systems (ITS) and variable message signs (VMS) are more frequently used throughout 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.

Modern technology is used to improve the information for drivers when approaching a work zone / work zone vehicles or when driving within the work zone. Some examples were stated in the interviews:

- Netherlands: Maintenance and intervention vehicles are equipped with a button to transmit locations. Drivers receive notification of this intervention on their navigation system instantly
- Germany: lorry drivers (long distance drivers) receive information on work zones via CB signal in different languages – traffic signs and barriers of work zones are equipped with signals.
- UK: 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.

An indication of deviation and estimated travel times is information that can be provided with the help of sensors and variable message signs as well. Road works usually cause a capacity reduction and increased travel times. Travel times can be calculated accurately using Google Maps and be displayed on VMS. 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 12: 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*

In addition to fixed, existing gantries and ITS devices, portable solutions can be used.

If queues are anticipated to occur during some portion of the work shift, e.g. on roads with a high traffic volume, portable real-time end-of-queue warning systems are an option to reduce rear-end collisions in work zones. In the USA a system based on easily deployable radar speed sensors was used and 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. 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 13: 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

Ullman et al. (2017) stated that the use of end-of-queue warning system and portable rumble strips reduced collisions at interstate work zones and that the crashes that occurred were less severe than without the measures. During queuing and congestion, the use of the countermeasures appeared to reduce accidents by 53 % to 60 % compared to what would have been expected if the measures had not been used. Additionally, it was indicated that the use of portable rumble strips alone resulted in the same crash reduction as the combined measures, suggesting that there was little additional benefit to using end-of-queue warning system and portable rumble strips together.

A portable congestion warning dynamic message sign was evaluated in before/after field trials 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 just before the road work zone) 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, indicating a congestion. 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. UK 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 14: Example for information on alternative / diversion routes

Source: Wikimedia

Information about alternative routes should be clear and easily understood.


Source: FSV, RVS 05.02.12 (2014)

Use of simple, clear and readable signs


Source: KFV

Information about detour not readable, confusing
⇨ not clear

Figure 15: Examples of information on alternative route

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.

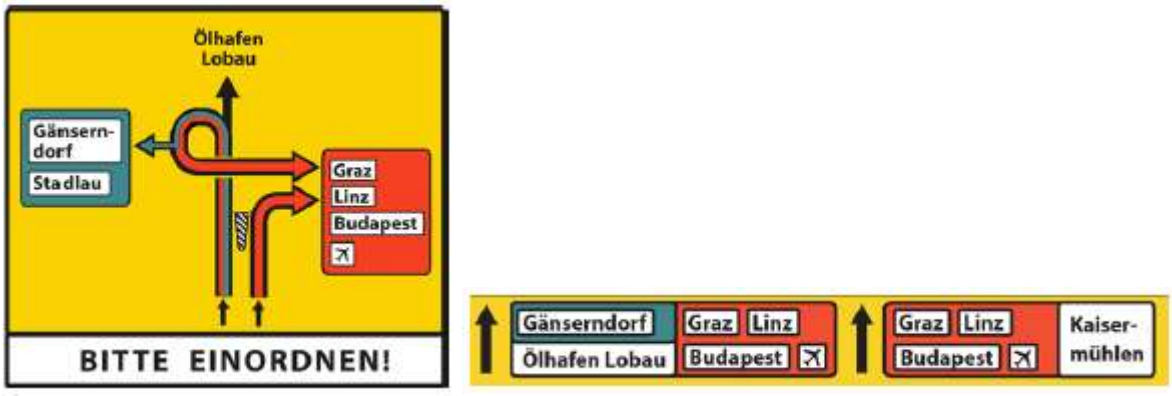



Figure 16: Example for using colours as additional information on alternative route

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.


Figure 17: Example for information that navigation system is not reliable, Netherlands

Source: https://www.wegenforum.nl/viewtopic.php?t=18231

### *4.3.5 Safety panels*

The type of safety panels used is mostly defined in national guidelines. Germany introduced panels with arrows instead of stripes, with satisfactory results. Arrow panels are regularly used in other countries already.

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.

| | |
|---|---|
|  Source: KFV |  Source: KFV |
| Similar types | Use of different types of safety panels |

Figure 18: Use of safety panels within a work zone

### *4.3.6 Portable rumble strips*

Portable rumble strips can be used on various occasions: applied on the driving lane while approaching a work zone it may be a speed reduction measure, 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 lane. In some countries portable rumble strips are also used for lane closing, additionally to safety panels.

There are several maintenance, effectiveness and environmental considerations (e.g. noise) effected by this measure. UK 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 within the work zone guidelines.

Figure 19: Portable rumble strips on hard shoulder

Source: www.maibach.com

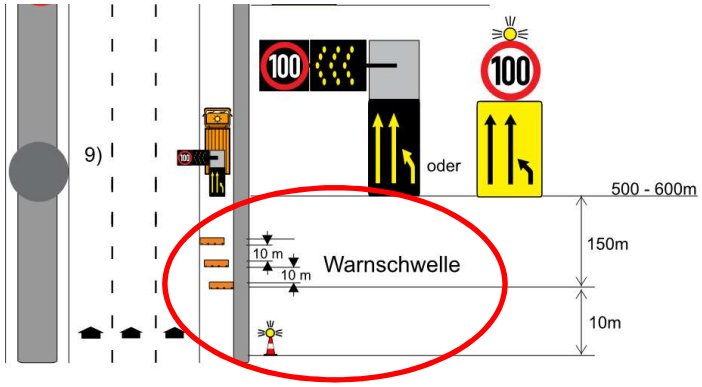



Figure 20: Principles of deploying portable rumble strips on hard shoulder

Source: FSV (2018), RVS 05.05.42, Road Work Zone Traffic Control, Roads with Separate Directional Carriageways

However, there is a risk to the roadworker who has to put the rumble strips in place. To limit the risk safety measures during application of the devices themselves are needed. Therefore, automated systems for deployment of the devices are desirable.

## 4.4 Speed management, enforcement

### 4.4.1 Average speed control, speed cameras

Enforcement of speed limits generally has a positive effect on traffic safety. As stated in the SafetyCube project, *"there is ample evidence that both section control* [i.e. average speed control] *and fixed speed cameras improve road safety."*[2] 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 in work zones is already used in the UK, 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.

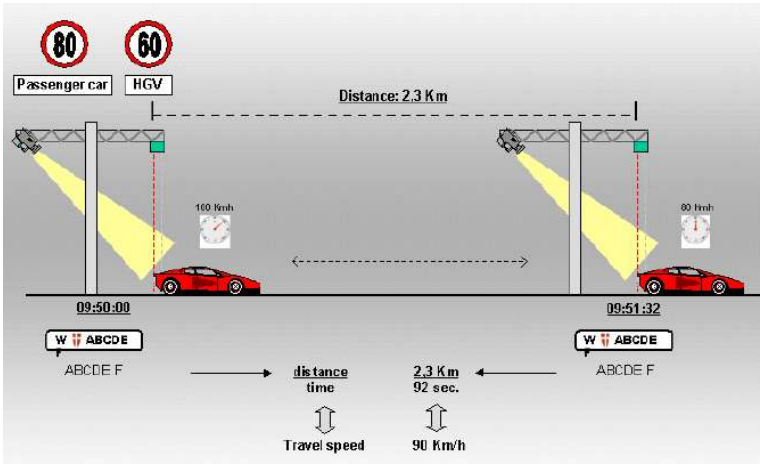



Figure 21: Scheme of average speed control

Source: Stefan, C. / Vienna Municipal Department 34, 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.

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

### 4.4.2 Use of dynamic speed display signs

According to the SafetyCube project, dynamic speed display signs (DSDSs) have favourable effects on speeds. One study also showed a decrease of the number of crashes after installing dynamic speed display signs.[3]


Figure 22: Dynamic speed display signs

Source: https://www.streetsmartrental.com/products/radar-speed-trailers-rental.html/

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 knowledges are necessary.

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 in work zones as well. Again, the devices should be put behind barriers or be collision friendly.

### 4.4.3 Temporary or variable speed limits in work zones

In Sweden and the UK temporary speed limits in work zones are sometimes used. When the work shift is over temporary speed limits or advisory speed signs are only to be left in place if roadway restrictions still present hazard to road users.

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


Figure 23: 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/

This measure can only be applied if local circumstances are in favour of the measure. However, in many cases speed limits are applied for road user safety and need to remain in place whether workers are present or not.

Another feasibility is to change the speed limit, e.g. when the work shift is over. This might be a possibility to enable drivers to pass the work zone faster, when no workers are around and thus the risk of accidents with workers does not apply. A device to show different speed limits at separate times would be variable speed limit signs.

Variable speed limit signs that are equipped with sensors to monitor traffic flow could also be used to adjust local speed limits according to oncoming traffic. This approach is already sometimes used in the USA However, the risk of higher permitted speeds must be assessed before application at a work zone. Further, an accurate record of when which regulatory speed limit was applied is essential for enforcement reasons and for evaluation of the safety of the measure.


Figure 24: Variable speed limit sign in work zone

Source: https://www.fhwa.dot.gov/publications/publicroads/03jan/10.cfm

## 4.5 Protection & lighting

### 4.5.1 Use of vehicle restraint systems

Best way to reduce incursions into work zones is a physical barrier (steel, concrete) between work zone and road. 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 25: Small temporary vehicle restraint systems

Source: KFV

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 26: Quick moveable barrier and vehicle for application/moving of barriers

Source: KFV

In the USA another mobile system has been developed. The mobile barrier 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 27: Work behind mobile barrier (left) and crash test of system (right)

Source: www.mobilebarriers.com

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 28: Water-filled portable vehicle restraint systems

Source: www.jtitraffic.com

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


Figure 29: 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 the UK 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 within these areas.

Figure 30: 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 Use of LEDs, flashing lights*

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

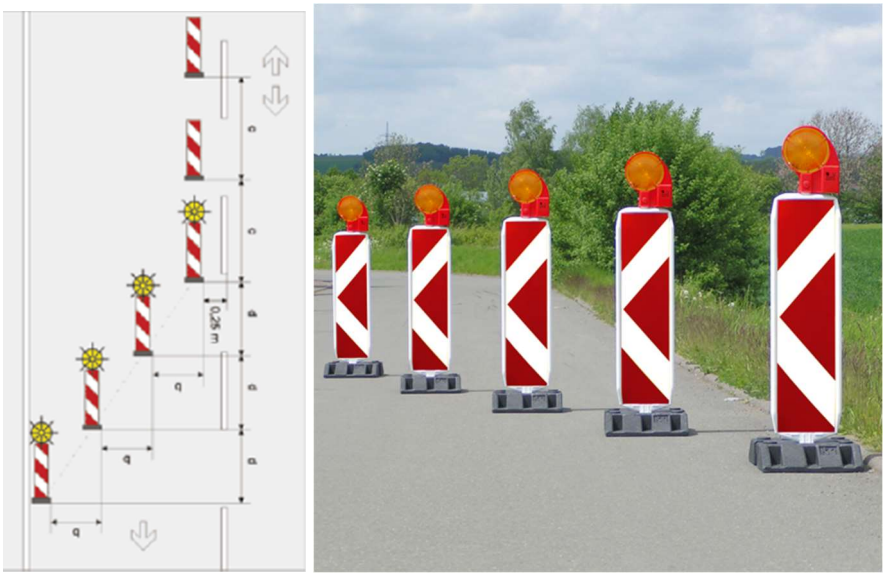



Figure 31: Running lights

Source: BRoWSER-Project (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 depending on weather conditions and time of day is desirable, as too bright lights can cause temporary blindness.

Figure 32: TMA, equipped with crash cushion and various LEDs (beacon bars, work lights, strobes)

Source: www.roadsafety.co.uk

### *4.5.5 Incursion detection*

Several systems of incursion detection are provided by different producers. 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. cones, barriers) is moved or destroyed.

However, Wang et al. (2013) in a national survey in the USA found that the application and effectiveness of Intrusion Alert Systems 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.

In the UK incursion detection systems are sometimes used as well.

## *4.6 Other measures*

### *4.6.1 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 gaps), can be done.

Figure 33: Temporary bridge (fly over)

Source: https://www.wien.gv.at/verkehr/brueckenbau/baustellen/flyall.html

### 4.6.2 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.

### 4.6.3 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 34: 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 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 zone.

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) 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 (BRoWSER, 2015).

Details about this database and its implementation can be found in the deliverable ‘CEDR BRoWSER D11_1 EuRoWCas - Guidance and information for NRAs - April 2015’.

# 6 Recommendations

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

- **Shift from "cheapest offer" to "best offer"**, wherein safety, as a broad topic, is an integral part of the offer.
- **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.
- **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.
- **Establish procedures** – carry out formal Work Zone Road Safety Audits and Work Zone Road Safety Inspections.
- **Reduce speeding** – enforcement, average speed control, appropriate speed levels at different times to enhance the acceptance, providing information on current driving speed,…
- **Keep the signing clear** – enough and early enough information, but only the information necessary; guide the drivers through the work zone.
- **Use symbols, images, pictograms** – to make it clear and understandable for everyone throughout Europe (and harmonise these signs all over Europe…).
- **Use vehicle restraint systems** – whenever possible, keeping in mind EN 1317.
- **Keep adaptation needs of the eye in mind** – illumination of critical zones and use of LEDs can improve safety, but there are limits for the eye… regulations regarding light intensity must be considered.
- **Use collision friendly devices** – whenever new devices are used they should not be obstacles themselves.
- **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.
- **Collect data** on all incidents and accidents in work zones. The EuRoWCas database was developed specifically for this purpose. It should be determined why most National Road Administrations do not use this format in order to propose further actions.
- **Include** behaviour and signalisation related to **work zones in driving education.**

# 7 References

ASAP - Appropriate Speed Saves all People, CEDR Project (2014)
http://www.cedr.eu/strategic-plan-tasks/research/cedr-call-2012/call-2012-safety/

Baumeister, R.F., Campbell, J.D., Krueger, J.I. & Vohs, K.D. (2003). Does high Self-esteem cause better performance, interpersonal success, happiness or healthier lifestyles? Psychological Science in Public Interest, Vol.4, n°1

BRoWSER - Baselining Road Works Safety on European Roads, CEDR Project (2015)
http://www.cedr.eu/strategic-plan-tasks/research/cedr-call-2012/call-2012-safety/browser-project-results/

Daalmans, J. (2014) Veilig werkgedrag door Brain Based Safety. Syntax Media, Utrecht

Douwes, M., Hooftman, W., Kraan, K., Steenbeek, R., Venema, A., de Vroome, E., Eysink, P., van der Molen, H., Frings-Dresen, M. & van den Bossche, S. (2014), Arbobalans 2014, kwaliteit van de arbeid, effecten en maatregelen in Nederland. TNO, Leiden

Fedris, (2017), Sectorfiche Weg- en waterbouw – NACE 42. Federaal agentschat voor beroepsrisico's via www.fedris.be

FSV – Forschungsgesellschaft Straße-Schiene-Verkehr (2018), RVS 05.05.42, Road Work Zone Traffic Control, Roads with Separate Directional Carriageways

Kahneman, D. (2012) Thinking, fast and slow. Penguin Books Ltd.

Lee, Y-C, White, W.A., & Velinsky, S.A. (2004) Integration and Testing of a Multistack Automated Cone Machine. UCD Dept of Mechanical & Aeronautical Engineering, California

PIARC (2012) Improvements in safe working on roads. 2012R29EN. World Road Association
https://www.piarc.org/en/order-library/18274-en-Improvements%20in%20safe%20working%20on%20roads.htm

Rankin, H.A., Abrams, T., Barry, R.J., Bhatnagar, S., Ckayton, D.F., Colombo, J. & Thompson, R.F. (2009) Habituation revisited: An updated and revised description of the behavioral characteristics of habituation. Neurobiology of Learning and Memory 92(2), p.135-138

Sharot, T., Korn, C.W. & Dolan, R.J., (2011) How unrealistic optimism is maintained in the face of reality. Natural Neuroscience, 11-09

Slootmans, F. & Daniels, S. (2017) De dodelijke tol op autosnelwegen. Analyse van de dodelijke verkeersongevallen op de Belgische autosnelwegen in de periode 2014-2015. (The deathly toll of motorways. Analysis of fatal accidents on Belgian motorways 2014-2015, in Dutch/French). Brussels, Belgium. Vias institute

Sörensen, G., Wiklund, M. (2010) Åtgärder för att minska hastighet förbi vägarbetsplatser. Utvärdering baserad på tre fältförsök. (Measures to reduce speed past road work zones. An investigation based on three field tests. In Swedish). VTI rapport 698, Swedish National Road and Transport Research Institute, Linköping, Sweden

Statens vegvesen (2011) Temaanalyse av trafikkulykker i tilknytning til vegarbeid. Basert på data fra dybdeanalyser av dødsulykker i vegtrafikken 2005-2009. (Thematic analysis of traffic accidents associated with roadworks based on data from in-depth analyses of road accidents in road traffic 2005-2009, in Norwegian). The Norwegian Public Roads Administration

Stefan, C. (2006) Section Control – Automatic Speed Enforcement in the Kaisermühlen Tunnel (Vienna, A22 Motorway), Austrian Road Safety Board, Vienna, Austria

Trafikverket (2016) Trafikolyckor vid vägarbeten 2003-2015. (Traffic accidents at road works, in Swedish). Publication: 2016:122. Swedish Transport Administration

Ullman, G.L., Pratt, M., Geedipally, S., Dadashova, B., Porter, R.J., Medina, J. & Fontaine, M.D. (2017). Analysis of Work Zone Crash Characteristics and Countermeasures. National Cooperative Highway Research Program, Transportation Research Board, Washington DC – Web-Only Document 240

Ullman, G.L., Fontaine, M.D., Porter, R.J. & Medina, J. (2018). Estimating the Safety Effects of Work Zone Characteristics and Countermeasures. National Cooperative Highway Research Program, Transportation Research Board, Washington DC

Wang, M.H., Schrock, S.D., Bai, Y., Rescot, R.A. (2013) Evaluation of Innovative Traffic Safety Devices at Short-Term Work Zones. Report No. K-TRAN: KU-09-5R. The University of Kansas, USA