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State of the Art on Speed Management Methods
Deliverable 2.1
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ASAP
Appropriate Speed Saves all People

Deliverable 2.1: State of the Art on Speed Management Methods

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EXECUTIVE SUMMARY

A review of work zone speed limits was conducted for several European Countries, Canada, the United States, and Australia. The review is the first technical activity in the ASAP project to establish the state-of-the-art for setting speed limits, identifying their effectiveness, and evaluated enforcement strategies, especially graduated fixed penalties.

Over 270 technical documents were collected and reviewed by the project team. The most relevant documents have been summarized and reported in this document. The information has been grouped under three main themes: Criteria for Setting the Most Appropriate speed in Work Zones (Chapter 3), Methods Used to Manage and Control the Speed of Vehicles in Road Work Zones (Chapter 4), and a Review of Graduated Fixed Penalties Programs (Chapter 5).

A number of criteria were determined that are used for assigning a work zone speed limit. They were:

- Original posted speed limit
- Type of road
- Impact on traffic flow
- Reduction of lane widths in the work zone
- Presence of workers
- Proximity of workers to the traffic passing
- Changes in road surface properties
- Presence of crossovers and changeovers
- Duration or length of road works

Although some of the criteria listed above are used by countries to assign work zone speed limits, there is a great deal of variation in how the factors are used to define speed limits. Some countries have documents describing small speed reductions (in line with the Migletz (1998) results), but others used multiple levels of 20 km/h (or higher) speed reductions. Another issue with the existing guidelines is that many speed limits are not automatically assigned but are based on the judgment of the analyst. Many documents refer to subjective interpretation of the conditions and there is no easily identified nomograph, flowchart, or similar procedure that can objectively determine appropriate speed limits. Further analysis with actual speed and safety data is needed to determine if any uniform work zone speed limits can be derived in a generic guideline for Europe.

Of the criteria listed above, the elements most common in the reviewed documents (in descending response frequency) were:

1. Road Type
2. Original Posted Speed
3. Workers Present or Proximity to Workers
4. Duration or Length of road works
5. Lane Width

Several methods have been used for controlling work zone speeds. These methods can be information (signs, flaggers, etc.), physical systems (rumble strips, chicanes, lane width restrictions, etc.), and enforcement (police presence). All of these methods have shortcomings in terms of effects. Some of the most promising are those related to speed monitoring and variable message signs where the driver is provided real time information on their speed and implication of speeding. Static traffic signs appear to provide some speed management effects but there were no consistent results in the different documents reviewed. Police presence had some of the largest effects but only when the police presence was connected to active enforcement activities.
The main conclusion from the speed management review was that work zone speeds tended to have more uniform speed distributions, but only small reductions in average speeds were found without an element of a dynamic implementation (variable messages, police enforcement).

Graduated Fixed Penalties is a system where speeding penalties (fines, license demerit points, suspensions, etc.) are increased from standard levels for infractions in work zones. This system is exclusive to North America and a summary of fines and effectiveness are presented in Chapter 5. The effectiveness is variable and essentially equivalent to the other speed management methods reviewed in Chapter 4. Active, on-site enforcement appears to be the best method to apply this approach. Drivers are not responsive to static information that does not have immediate repercussions or feedback.

The reviewed documents had little detailed safety information that can be used to evaluate the different speed limits, speed management, or enforcement approaches in terms of work zone injuries and fatalities. There is information on general work site casualty rates based on annual statistics but detailed analyses were not identified in any of the reviewed documents.
1 INTRODUCTION

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

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

The ASAP project runs from February 2013 to January 2015 with funding from the CEDR “TRANSNATIONAL ROAD RESEARCH PROGRAMME Call 2012 - Safety: Safety of road workers and interaction with road users”. There are four main activities that will collect analyse and propose harmonised work zone using both European and global work zone safety data available to the project team.
2 OVERVIEW OF THE REPORT

This deliverable is the result of the activities conducted in Work Package 2, Review of Speed Management Methods, of the ASAP Project. The objective was to produce a state of the art report identifying the different criteria adopted worldwide for setting and controlling speed in work zones.

The information presented in the deliverable is based on a joint literature review conducted by all partners. The literature was collected by searches of internal databases hosted by the partners, international databases such as TRID which includes the Transportation Research Information Service (TRIS) and the International Transport Research Documentation (ITRD). Database queries used key words like: speed, work zone, roadwork, construction site, crash, accident, injury, layout, design, speed control, speed enforcement, traffic management, etc. Other personal contacts by the partners were used to gather information from countries surrounding the partner organizations.

The different reports identified by the partners were compiled and any duplicates were eliminated. Each partner was then assigned specific articles to summarize so that a final document could be compiled and reported for the project team.

Within this work package, about 270 documents were collected, reviewed and inserted in an unique database (Figure 2-1) where all the documents have been classified based on the main topic, the authors, the title, the references, the year of publication and the status (“ongoing” project or “completed”). The complete database can be downloaded from the ASAP website (http://asap.fehrl.org/)

Figure 2-1: Literature Review Database

The report is structured in 3 chapters, each addressing the activities conducted in the 3 different tasks of Work Package 2:

- Section 1 (Task 2.1) deals with the review of Guidelines and criteria for setting the most appropriate speed in work zones;
- Section 2 (Task 2.2): deals with the review of available literature regarding methods used to manage and control the speed of vehicles in road work zones
- Section 3 (Task 2.3): deals with the review of “graduated fixed penalties” for speeding at road work zones applications

Each chapter is presented with its own reference list and can be used as a separate document if desired.

Note that some countries have not adopted the metric system. This report provides all speed limits in km/h but provides the original speed limit in local units in parenthesis to avoid confusion when
referring to the original document. For example: “the speed limit of 16 km/h (10 mph)”. Empirical units for dimensions are also reported in both meters (m) and feet (ft).
3 CRITERIA FOR SETTING THE MOST APPROPRIATE SPEED IN WORK ZONES

3.1 Introduction

It is generally acknowledged that work zones are more hazardous than other sections of road. An area of a highway with construction, maintenance, or utility work activities is known as a work zone. Reasons for increased crash risk at work zones (especially for temporary work zones) relative to other road sections, include the unexpected and unfamiliar nature of specific work zones, deviations from driver expectations, and the presence of workers.

In the United States and the Netherlands, about 2% of road fatalities (SWOV, 2010) and 1.5-2% of all workplace fatalities occur in work zones (Pegula, 2004). New South Wales data (RTA, 2007) estimated that at least 50 deaths and 750 injuries result from road traffic crashes annually in Australian work zones.

The extensive network of highways in the United States included more than 8.4 million lane miles of paved roads in the year 2005 (TSAR, 2007). This network continues to expand and requires constant maintenance. In 2006, The National Work Zone Safety Information Clearinghouse, reported 1 010 fatalities and over 40 000 injuries occurred within designated work zones (NWZSIC, 2008).

A report by Kansas State University (Dissanayake and Akepati, 2009) shows that of the 720 work zone fatalities in 2008 in U.S., speeding was a factor in 225 (31%) cases. Speeding is clearly a factor that contributes to traffic accidents and fatalities.

A poll of members of the American Association of State Highway and Transportation Officials (AASHTO) Highway Subcommittee stated that safety problem in work zones is aggravated by the lack of uniform guidelines for determining speed limits (Migletz, et al 1993). The inconsistencies in the methods used to determine work zone speed limits, the non-compliance with the posted speed limit by motorist, and the growing practice of setting work zone speed limits through administrative decisions without the support of an engineering study were identified as the major contributors to this safety problem.

A study conducted by Migletz et al (1993) shows that the safest traffic flow occurs when all vehicles are travelling at approximately the same speed, which means that the range of speeds is within a relatively narrow band (e.g. the pace range), and the speed variance is small. As speed variance increases, motorist crashes tend to increase. Furthermore the results show that the safest work zones are those with the smallest increase in the upstream-to-work-zone speed variance and that speed compliance in work zones is generally higher where the speed limit reduction is lower than 16 km/h (10 mph) (Migletz et al, 1993). The National Cooperative Highway Research Program (NCHRP) project 3-41 states that in rural freeways work zones without a speed limit reduction, the percentage of vehicles exceeding the speed limit was in general lower inside the work area than upstream on the average by 21.7% (Migletz et al, 1998) as shown in Figure 3-1. Furthermore they noticed that the percentage increase in speed variance, from upstream to work location, appears to have a minimum for a speed limit reduction of 16 km/h (10 mph). For work zones without a speed limit reduction, the speed variance in the work zone was 61% higher than the upstream speed variance (Figure 3-2).
Figure 3-1. Reduction in percentage of vehicles exceeding the speed limit from upstream to work zone (Migletz et al, 1998).

Figure 3-2. Increasing of speed variances in function of speed limit reduction (Migletz et al, 1998).

According to Figure 3-3 the minimum percentage of fatal-plus-injury accident rates during the construction period occurs for a speed limit reduction around 16 km/h (on rural freeways). Work zones without speed limit reductions had the next smallest percentage increase in the fatal-plus-injury accident rate, but not the minimum.

Figure 3-3. Increasing of fatal injuries in function of speed limit reduction (Migletz et al, 1993).
Many international guidelines recommend moderate speed reductions with the aim to achieve a higher degree of safety (Bham & Mohammadi, 2011). Speed limit reductions of more than 16 km/h (10 mph) were discouraged, since previous research had shown that motorists will not typically slow down more than 16 km/h (10 mph) through a work zone, even if enforcement is present.

A survey made by the Iowa Department of Transportation shows that twenty-one out of 39 responding American agencies indicated that they generally reduce work zone speed limits up to 16 km/h (10 mph) lower than the normal posted speed for the facility. Nine agencies mentioned that they even consider lowering the speed limits by up to 32 (20 mph) km/h (below the posted speeds). Speed limit reductions greater than 16 km/h (10 mph), however, generally require special reviews by the agency management. Four state agencies expressed their preference to avoid work zone speed limit reductions altogether. However, if the speed limits must be reduced because of physical constraints (e.g., close proximity of workers to traffic), their standard reductions are up to 16 km/h (10 mph) below the normal posted speed.

Six agencies stated that they consider speed limit reductions on a case-by-case basis. These reductions are based on site conditions and the nature of work activities being conducted. All state agencies surrounding the state of Iowa, except the Kansas Turnpike Authority, indicated having policies for speed limit reductions at work zones. These agencies generally reduce the speed limits at their work zones by 16 km/h (10 mph). However the amount of speed limit reduction to be implemented depends on many factors. Particular conditions of hazard could require higher reductions.

Various jurisdictions have their own methodology and guidelines for determining when and where regulatory speed limits should be used. Nevertheless, the low levels of compliance with reduced work zone speed limits continue to show the inconsistencies between current procedures for establishing regulatory work zone speed limits and actual motorist speed choice in work zones.

A review of the criteria for setting speed limits in work zones is presented in the remainder of this section. The review of national standards and guidelines covers most European countries and some non-European country such as U.S, Australia and Canada.

### 3.2 National and Regional Criteria for Setting Work Zone Speed Limits

#### 3.2.1 Ireland

Irish regulations (Ireland, 2004) state that traffic management arrangements should be designed on the basis of the permanent prevailing speed limit. The practice of introducing a road works speed limit for the express purpose of reducing the required lateral clearance (or other design criteria) is not encouraged. Where this exceptional provision is invoked (e.g., where roadway width is restricted by bridges, tunnels and other structures), provisions must be made in the Temporary Traffic Management Plan to encourage compliance with the work zone speed limit.

A work zone speed limit follows the steps of 30, 50, 60, 80 or 100 km/h and no others should be used. The work zone speed limit chosen should be, in general, not more than two speed limit steps below the speed limit posted outside the work zone and should be appropriate to the speed at which a vehicle could drive through the work zone with reasonable safety. It should be the design speed applicable for the geometric layout of the traffic through the works. However, on high-speed roads it may not be practical or appropriate to install a layout with a low geometric design speed. In this case the speed limit should, provided the site specific risk assessment does not require otherwise, be reduced by a maximum of two speed limit steps below the posted speed. Further reductions may be warranted at specific locations such as a crossover. Irish regulation states that it
could be appropriate to apply a reduced work zone speed limit through the counter-flow operation, to accommodate the reduced geometric design standard of the crossover.

One of the principal factors influencing the horizontal and vertical geometric design is the achievable design speed. Where possible, the design speed and work zone speed limit to be applied for the crossover should be the same as the speed limit applied to the rest of the work zone. In some circumstances it may be necessary to apply a lower work zone speed limit over the length of the crossover to accommodate the achievable design speed. It should be noted that the minimum speed limit permissible is 50 km/h on motorways and the minimum permissible work zone speed limit is 30 km/h.

The design of temporary traffic measures in Ireland is based on a combination of six road classifications shown in Table 3-1 which includes the work zone speed limits (as primary criteria) and five roadwork types:

- Full-time road works;
- Part-time road works;
- Road works that are of a short duration and involve the use of one or two vehicles;
- Semi Static Lane Closure (SSLC);
- Mobile Lane Closure (MLC).

Table 3-1. Work Zone Posted Speed Limits for Different Road Types

<table>
<thead>
<tr>
<th>Road Classification</th>
<th>Type of Road</th>
<th>Speed Limit</th>
<th>Traffic Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
<td>Single Carriageway</td>
<td>30 km/h</td>
<td>All Traffic Volume</td>
</tr>
<tr>
<td>Level 2</td>
<td></td>
<td>50 or 60 km/h</td>
<td>All Traffic Volume</td>
</tr>
<tr>
<td>Level 3</td>
<td></td>
<td>80 or 100 km/h</td>
<td>ADT &lt; 5000 vpd</td>
</tr>
<tr>
<td>Level 4</td>
<td></td>
<td>80 or 100 km/h</td>
<td>ADT &gt; 5000 vpd</td>
</tr>
<tr>
<td>Level 5</td>
<td>Dual Carriageway and Motorway</td>
<td>50, 60 or 80 km/h</td>
<td>All Traffic Volume</td>
</tr>
<tr>
<td>Level 6</td>
<td></td>
<td>100 or 20 km/h</td>
<td></td>
</tr>
</tbody>
</table>

Depending on the road work layout, a speed limit lower than those given in Table 3-1 can be used.

Irish regulation requires that for works of short duration, short length, or due to an emergency where it is not appropriate or practicable to impose a mandatory work zone speed limit, a cautionary speed may be applied. A cautionary speed sign does not require a governmental order, but the designer should consult with the Road Authority before implementing the temporary traffic measures. The speeds are deliberately different from the regulatory speed limits and shall be one of: 25, 35, 45, 55, 65 or 75km/h. Very slow speeds should not be used unless absolutely necessary.

3.2.2 Belgium

In Belgium (Belgium, 1999), the legal basis for the categorisation of work zones is determined by the decree of May 7th, 1999 concerning the signing of road work zones and other obstructions on
public roads. The regulation mentions the measures (including speed limits) that should be applied for each category of road works and, within each category, for each work zone.

- Category 1: road works on motorways and roads with a posted speed limit above 90 km/h
- Category 2: road works on roads with a posted speed limit between 50 and 90 km/h
- Category 3: road works on roads with a posted speed limit not above 50 km/h
- Category 4: works planned outside the traffic area but hindering pedestrians and other vulnerable road users
- Category 5: works during daylight conditions and with normal visibility (200m)
- Category 6: mobile road works hindering the traffic due to their low speed of frequent stops.

On motorways the standard speed limit is 120 km/h and, for Category 1 road works having a severe impact on traffic, the speed limit is steeply decreased in the advance warning area typically from 120 km/h to 90 km/h 1100 m upstream of the work zone to 70 km/h 500 m upstream of the work zone. This may be eventually followed by a 50 km/h speed limit according to the local circumstances.

Following the Belgian decree (Belgium, 1999) the road category, the standard speed limit and the impact on traffic flow are therefore the main criteria used to set temporary speed limits in the advance warning area. For road works having a moderate impact on the traffic flow, the lane width reduction is used as additional criterion. The federal regulation is complemented by regional guidelines which give additional details concerning the measures to apply with respect the existing federal categorization.

The regional guideline (standard tender specifications) used in Wallonia (WRA, 2013) requires that Category 1 road works having a severe impact on traffic flow and a crossing of the central reserve must have the speed limit must be reduced up to 50km/h (100m upwards the lane deviation). This is a common practice in Belgium for such road work layouts.

The standard tender specifications used in Flanders (FRA, 2012) require that Category 2 road works having a speed limit of 50km/h when there are moderate impacts on traffic flow and lane widths narrower than 3.25m. Category 3 road works having a moderate impact on traffic flow and lane widths ≤ 3m locally have speed limits fixed to 30km/h. Similarly, the Walloon specifications (WRA, 2013) require Category 2 road works with moderate impacts on traffic flow and lane widths ≥ 3m to have speed limits of 70km/h (instead of 50km/h in other circumstances).

### 3.2.3 France

Part number 8 of the “Instruction interministérielle sur la signalisation routière: Signalisation temporaire”, (France 2012) defines the temporary speed limit distinguishing between single carriageway roads (bidirectional) and dual carriageway roads (including motorways). It states that a temporary speed limit is usually not necessary in build-up areas where the permanent speed limit equals 70 km/h, except:

- on 70 km/h roads when a 50 km/h temporary speed limit is necessary due to capacity reduction (lanes closed);
- in sub-urban areas and crossing of small sized built-up areas, where a 50 km/h reminder is often necessary;

Furthermore it defines the temporary speed limit as a function of the number of lanes that remain open to traffic as follows:

- On single carriageway roads (bidirectional):
  - ≤ 70 km/h when 2 lanes remain open;
  - ≤ 50 km/h when the traffic flows alternates on 1 single lane;

- On dual carriageway roads (including motorways):
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- ≤ 90 km/h when only 1 lane remains open on 3 lanes (or more) roads with a permanent speed limit equal to 130 km/h;
- in all other situations, the temporary speed limit is maximum 20 km/h below the permanent speed limit.

In cases of lanes with reduced width on dual carriageway roads and along sections with counter-flow traffic, speed limits should be:

- ≤ 90 km/h when the permanent speed limit equal to 130 km/h or 110 km/h;
- ≤ 70 km/h when the permanent speed limit equal to 90 km/h.

Instructions on road signs (France 2012) state that in built-up areas where the permanent speed limit equals 50 km/h a temporary speed limit is always necessary when road workers are operating on (or close to) the carriageway or when the traffic trajectory is significantly modified due to the road work presence.

Guidelines from SETRA (2002), concerning temporary signing of work zones, define a temporary speed limit as a function of the length of the work zone length. If the length is greater than 50 meters the posted speed limit should be not higher than 70 km/h, otherwise of 50 km/h should be used for shorter work zones.

### 3.2.4 Luxembourg

Legislation of Luxembourg (2009) distinguishes speed limits along active road works within built areas. Within built-up areas the standard work zone speed limit is 50km/h. It can be reduced to 30 km/h under exceptional circumstances like an uneven carriageway profile, infrastructure deficiencies, important narrowing, etc. Outside built-up areas the standard work zone speed limit is 70 km/h on 3 lanes carriageways when 1 lane is closed or narrowed and on 2 lanes carriageways when 1 or 2 lanes are narrowed. The standard work zone speed limit is 50km/h on 2 lanes carriageways when 1 is closed. It can be reduced to 30 km/h under exceptional circumstances, like an uneven carriageway profile, infrastructure deficiencies, important narrowing, etc.

On motorways in Luxembourg the standard work zone speed limit is 70km/h. The speed limit is steeply decreased (90 - 70 km/h) from the speed limit outside the work zone (130 km/h).

### 3.2.5 Netherlands

In the Netherlands (CROW, 2013) the standard work zone speed limit is generally 90km/h on motorways but in special situations it can be reduced to 70 km/h. In temporary situations, and if possible, the speed limit could be 100 km/h. However outside motorways the limit is reduced to 70, 50 or 30km/h. Legislation of Netherlands (CROW, 2013) requires also different limits depending on the work duration. It identifies four different categories:

- Very short if time required is less than 30 minutes;
- Very short if time required is included between 30 minutes and 2 hours;
- Long if time required is included between 2 hours and 1 day;
- Very long if time required is more than 1 day.

Work zones away from traffic generally need fewer measures than those directly next to or on the roadway. The distance between the workspace and traffic determines the choice of measures. Work zones on motorways are divided into different situations, based on their position on the road. In Table 3-2 speed reductions during work in progress on roads are shown.
Table 3-2. Criteria for Speed Reduction in the Netherlands (Crow 2013)

<table>
<thead>
<tr>
<th>No Traffic Barriers</th>
<th>Traffic Barriers</th>
</tr>
</thead>
<tbody>
<tr>
<td>road workers behind closed guardrails</td>
<td>road workers behind open guardrails</td>
</tr>
<tr>
<td>‘open’ separation between work zone and road, but no activities or no machines or other obstacles in the work zone</td>
<td>‘open’ separation between work zone and road, and activities and/or machines or other obstacles in the work zone</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Posted speed limit</th>
<th>Work Zone Speed Limit</th>
<th>Work Zone Speed Limit</th>
<th>Work Zone Speed Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>100km/h</td>
<td>100km/h</td>
<td>70km/h</td>
<td>70km/h (or 50km/h with temporary traffic lights on reversible lane)</td>
</tr>
<tr>
<td>80km/h</td>
<td>80km/h</td>
<td>50km/h</td>
<td>50km/h</td>
</tr>
<tr>
<td>70km/h</td>
<td>70km/h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60km/h</td>
<td>60km/h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50km/h</td>
<td>50km/h</td>
<td>30km/h</td>
<td>30km/h</td>
</tr>
<tr>
<td>30km/h</td>
<td>30km/h</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Norway**

The Norwegian handbook (Hauge, et. al, 2012) provides the following guidelines for choosing temporary speed limits for work zones:

- 70 km/h in addition to speed reducing measures can usually be adopted on roads with posted speed limits higher than 80 km/h.
- 60 km/h can be used on roads where ordinary speed limits before the roadwork is 70 km/h, or if a risk assessment shows that 70 km/h is too high.
- 50 km/h can be used:
  - for shorter stretches due to poor geometry or road surface condition,
  - in approaches to temporary traffic lights and
  - on roads where ordinary speed limit before the roadwork is 70 km/h.
- 30 km/h is always used in combination with speed-reducing measures:
  - for short stretches (<300 m) or short periods with workers near the carriageway
  - very short stretches if road standard due to roadwork is poor
  - if traffic flow capacity is sufficient
Additionally the handbook states that:
- 50 km/h should not be used for stretches longer than 1 km;
- speed limits of 60 km/h can be used towards temporary traffic lights (length \(\leq 300\) m);
- 70 km/h work zone lengths may not be longer than 5 km.

According to the Norwegian handbook (Hauge, et. al, 2012), the need to lower the speed limit in connection with workzones shall be evaluated on the basis of the concern for the workers and the road users. Additional speed reducing measures should also be considered such as:
- Work on the carriageway
- Distance between workers/machinery and passing vehicles
- Changes in the alignment that dictates lower speed limit
- Risk of loose chippings or slippery road surface

There shall always be a buffer zone in front of a worksite even if only warning equipment and no protective equipment is used. This zone shall be free from all kinds of obstacles, people, machinery and equipment. The buffer zone's length will depend on the expected speed level in the case of collisions and the type of protective equipment used. The length shall be specified in the roadwork safety plan. There shall also be a longitudinal safety zone alongside the carriageway where there must be no people and no hazards such as deep pits, steep slopes and heavy objects. The width of the safety zone, measured from the end of the carriageway (white road marking), ranges from 3 m when speed limit is lower than 50 km/h to 10 m when 100 km/h work zone speed limits are used (Table 3-3). Road workers shall not work closer than 3 m to the edge of the carriageway for more than one hour when the speed limit is over 50 km/h if they are not protected by guardrails or are in a machine.

<table>
<thead>
<tr>
<th>Speed limit (km/h)</th>
<th>&lt;=50</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety Zone (m)</td>
<td>3</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
</tr>
</tbody>
</table>

Additional protective measures such as guardrails or a lower speed level must be used if the following hazards can be found within the safety zone:
- construction pits deeper than 1 m,
- steep slopes, height differences that should normally be protected with guardrails,
- heavy objects that are dangerous to collide with in the case of driving off the road (rock faces, construction machinery, structures, etc.).

Work in tunnels longer than 500 m shall take place with the aid of manual traffic control and a convoy escort vehicle. For tunnels less than 500 m long a speed reduction must be signed.

3.2.6 Denmark

A pending edition of the Danish handbook for marking of work zone, dated May 2012, from the Danish Road Directorate (Vejdirektoratet, 2012), proposes temporary speed limits and levels of protection depending on road environment for different types of moving and stationary work zones. There are 8 levels of protection for intermittent (moving) work zones in this handbook:

1. Speed limit 20 km/h and speed reducing measures when there are workers on the road
2. Edge markings or delineators
3. Safety zone \(\geq 1\) m including width of edge markings
4. Protection module: vehicle or machinery \(\geq 7\) t
5. Work zone exclusively in the vehicle or machine
6. Traffic protection or impact absorber
7. Secondary traffic protection or traffic protection without deflection
8. Closing the whole road or one carriageway if the road has a central reserve
Danish guidelines for markings of work zone (Vejdirektoratet, 2002) identify different layouts and speed limits for the following cases:

- For stationary roadwork that takes place off the carriageway, the temporary speed limit should be lower than 50 km/h.
- For stationary roadwork on roads and streets with 2 lanes or less, maximum original speed limit is 50 km/h.
- Stationary roadwork on roads with 2 lanes, maximum original speed limit higher than 50 km/h
- Stationary roadwork on roads with 3 lanes or partly 3 lanes: speed limit lower than 50 km/h
- Stationary roadwork on roads with 4 lanes or more, with a central reserve or double continuous line in the horizontal marking, maximum original speed limit ≤ 80 km/h, except for:
  - Work on crawler lane and hard shoulder: light protection and safety zone ≥1m, temporary speed limit higher than 70 km/h
    - One lane closed: longitudinal markers and safety zone ≥1m, temporary speed limit lower than 50 km/h
    - Left lane closed: longitudinal markers and safety zone ≥1m, temporary speed limit lower than 50 km/h
  - Stationary roadwork on roads with 4 lanes, with a central reserve, maximal original speed limit ≥ 90 km/h
    - Work on crawler lane and hard shoulder: light protection, speed limit >90km/h
    - One lane closed: longitudinal markers and safety zone ≥1m, temporary speed limit lower than 70km/h
    - One lane closed: traffic protection, temporary speed limit lower than 70km/h
    - One lane closed: paving machine, longitudinal markers, temporary speed limit lower than 70km/h
    - Both lanes closed: use of opposite direction, light protection, temporary speed limit lower than 70km/h
  - Stationary roadwork. Roads with 6 lanes or more, with a central reserve, maximal original speed limit ≥ 90 km/h
    - One lane closed: Longitudinal markers and safety zone ≥2m – ≤ 70 km/h
    - Two lanes closed. Use of one lane in opposite direction, safety zone ≥2m – ≤ 70 km/h
  - Stationary roadwork with additional markings.
    - Work on secondary road, road work warning, detour, interim road, temporary speed limit doesn’t change
    - Temporary lowered free height, photocell, speed limit doesn’t change
  - Stationary roadwork and specific situations:
    - Container on the road, barrier and pre-warning, speed limit ≤ 50 km/h
    - In crossing in town, barrier, speed limit ≤ 40 km/h
    - Stationary or intermittent roadwork, digging/excavation, without traffic protection, only cones, markers, speed limit ≤ 50 km/h
    - Cherry picker/scaffoldings, speed limit don’t change
- Moving roadwork:
  - Longitudinal marking (machine) on the carriageway, marking cones and warning signs ≤ 50 km/h
  - Work on carriageway, sign trailer, speed limit ≤ 50 km/h
  - Work in a well on the carriageway, barrier and pre-warning, temporary speed limit ≤ 50 km/h
  - Moving or short term roadwork: work on carriageway, pre-warning and sign trailer, temporary speed limit > 90 km/h
  - Moving roadwork: one lane closed, after channelized crossing, sign trailer. speed limit ≤ 50 km/h
The Danish guidelines for marking of work zone on motorways (Vejdirektoratet. 2008) state maximum speed limits allowed:

- Work on or from the shoulder lane
  - ≤130 km/h for moving work zones (also in the central reserve between median barriers but then only when 2+2 lanes), warnings on vehicle or sign trailer are required.
  - ≤130 km/h short time, warnings on vehicle or sign trailer are required.

- 4 lane motorway (2+2),
  - ≤50 km/h intermittent, slow lane, Truck Mounted Attenuator (TMA, Figure 3-4).
  - ≤70 km/h intermittent, fast lane+central reserve ('mid shoulder'), with TMA
  - ≤90 km/h intermittent in the slow lane or the fast lane+central reserve, with TMA, no crawler lane,
  - 70 km/h short time, slow lane–sign trailer, with TMA
  - ≤70 km/h short time, fast lane, with TMA
  - ≤70 km/h short time fast lane+central reserve, safety zone<3m, with TMA or ‘port’
  - ≤70 km/h short time, left lane+central reserve, with TMA
  - 6 lane motorway (3+3),
  - ≤70 km/h moving, right lane or left lane+central reserve ('mid shoulder'), with TMA
  - ≤70 km/h Short time, right lane+mid lane–sign trailer
  - ≤70 km/h short time, mid+left lane, TMA+sign trailer
  - 8 lane motorway (4+4),
  - ≤70 km/h short time, right lane or the left lane+central reserve – with TMA
  - ≤70 km/h short time, the 2 right or the two left lanes– with TMA+sign trailer

Figure 3-4. Truck Mounted Attenuator (TMA)

As in Norway, the speed limit shall not exceed 50 km/h when manual traffic control is used. Moreover, the Danish handbook (Vejdirektoratet, 2012) states that temporary speed limits should not be used when there is no on-going work.

The handbook defines speed limit dependent safety zones as shown in Table 3-4: the range varies from 2 m when 40 km/h to 11 m when 130 km/h.

Table 3-4. Speed Limit and Length of Safety Zone in Denmark (Vejdirektoratet, 2012).

<table>
<thead>
<tr>
<th>Speed limit (km/h)</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90</th>
<th>110</th>
<th>130</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety zone (metres)</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>9</td>
<td>11</td>
</tr>
</tbody>
</table>
Four classes of longitudinal protection between work area and traffic have been identified in the Danish regulations for markings of workzones (Vejdirektoratet, 2008):

- A - traffic protection;
- B - barriers per 6 meter except on roads with denser traffic then as A;
- C - edge marking plates or marking cones with light or marker pieces;
- D - edge marking plates or marking cones

Figure 3-5 shows the classes of recommended protection as functions of the width of the safety zone (m) and the speed (km/h). For example if the safety zone is 2 meters and the speed below 40 km/h then no longitudinal protection is needed. If the zone is 2 meters and the speed is higher than 70 km/h then a traffic protection is needed.

To give directions to traffic, Table 3-5 gives recommended speed limits of 40 or 50 km/h due to length of the work zone, sight distances at yielding location, and capacity (vehicles/h). For instance the sight distance should be at least 165 m if the work zone is 50 m long and the speed limit 50 km/h.

Table 3-5. Speed Limit as Function of Length of Work Zone, Sight Distance and Capacity (Vejdirektoratet, 2012)

<table>
<thead>
<tr>
<th>Length of work zone</th>
<th>Minimum sight distance</th>
<th>Capacity in both directions (veh/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Speed limit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>40 km/h</td>
<td>50 km/h</td>
</tr>
<tr>
<td>≤ 30 m</td>
<td>95 m</td>
<td>115 m</td>
</tr>
<tr>
<td>40 m</td>
<td>120 m</td>
<td>140 m</td>
</tr>
<tr>
<td>50 m</td>
<td>140 m</td>
<td>165 m</td>
</tr>
<tr>
<td>70 m</td>
<td>180 m</td>
<td>210 m</td>
</tr>
<tr>
<td>100 m</td>
<td>245 m</td>
<td>285 m</td>
</tr>
</tbody>
</table>
3.2.7 Sweden

The Swedish Guidelines (Trafikverket, 2012a) require different speed limits through work zones in function of the safety zone width. Safety zone widths at road works should be dimensioned as follows:

- Speed up to 50 km/h: at least 3 meters wide
- 60 km/h, at least 6 meters wide
- 70 km/h: at least 7 meters wide
- 80 km/h: at least 8 meters wide
- 90 km/h: at least than 9 meters wide
- 100 km/h, at least 10 meters wide
- 110 km/h, at least 11 meters wide
- 120 km/h: at least 12 meters wide

The Guidelines (Trafikverket, 2010; Trafikverket 2012a) provide suggestions for maximum actual speeds of vehicular traffic passing by or through the work zone, depending on the type of side barrier and the distance between the traffic and those who work on or beside the road. The guidance also applies to staff in unprotected machinery or vehicles such as road marking machines. It is important that the following maximum actual speeds are not exceeded for vehicular traffic passing by or through the area where the construction work (work zone) is carried out:

- 30 km/h if the lateral distance (distance between the staff and the road, or the nearest part of the lane) is less than 2.5 m;
- 50 km/h if the lateral distance is greater than 2.5 m (the distance from the 2.5 m, and the distance at which no risk of collision exists);
- 70 km/h if a protective safety barrier of at least class T2 according to EN1317-2 is used.

Furthermore Swedish guidelines (Trafikverket, 2012b) outline that unnecessarily long, closed road stretches, as well as long waiting times create irritation and reduce respect for traffic signs and road works. The length of road closures and waiting periods should therefore be kept as short as possible. If the temporary speed limit of 30 or 50 km/h is applied, it should only be used over a short distance and only when active work is in progress.

3.2.8 Austria

The Austrian guideline “RVS 05.05.43” (RVS, 2012) requires different speed limits for the various road types and depending on the particular lane width. For roads with separate directional carriageways it requires:

- Single lane:
  - < 3.25 m: 60 km/h (lanes only for passenger cars 80 km/h)
  - 3.25 m up to 3,50 m: 80 km/h
  - < 3.50 m : 100 km/h

- Two-lane:
  - <6 m: 60 km/h
  - 6 m up to 6,50 m: 80 km/h
  - <6,50 m : 100 km/h

For roads with two or more lanes per direction:

- < 3.25 m: 60 km/h (if the total width of two lanes is at least 6m: 80km/h)
- 3.25 m up to 3.50 m: 80 km/h
The document RVS 05.05.44 (RSV 2003) for roads with one lane per direction doesn’t specify a required speed limit, but the speed limits must be decided according to the local conditions in work zones. The Austrian ASFiNAG guide for traffic management and traffic safety in work zones (ASFiNAG, 2007) states that lane reduction should be avoided and if necessary speed limits must be adapted to the lane widths. The work zones must not start in curves or hill crest areas. There is a particular need for action in the design of entrances and exits. Table 3-6 shows the minimum widths of the lanes to be adopted as a function of the speed limit. In a discussion with ASFiNAG, in the near future a general speed of 80 km/h in work zones on the Austrian highway network should be achieved, due to specific work zone treatments.

Table 3-6. Minimum widths of lanes in function of speed limit (ASFiNAG, 2007).

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>60km/h</th>
<th>80km/h</th>
<th>100km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>trucks+cars</td>
<td>3.00m**</td>
<td>3.25m*</td>
<td>3.50m</td>
</tr>
<tr>
<td>Truck</td>
<td>2.50m**</td>
<td>2.50m**</td>
<td>3.00m</td>
</tr>
</tbody>
</table>

* Or the width of two lanes one direction at least 6.00 m;
** Absolute minimum widths, for longer durations at sites with a length of more than 6.0 km are recommended minimum lane width of 3.25 m (truck and car) and 2.75 m (cars);

### 3.2.9 Germany

German guidelines (BMV, 2009) require different regulations for particular types of roads. On ordinary highways the speed limit in work zones is 50 km/h, which must be preceded by a limit of 70 km/h (in exceptional cases 60/80 km/h). It’s recommended to keep the existing number of lanes. The number of lanes can be reduced if an alternating operation or a diversion is possible. As a rule, a minimum lane width of 2.75m is observed. For motorways the work zone information must be posted 2 kilometres and 800 m ahead. At work zones on motorways it is also recommended to keep the existing number of lanes. The number of lanes can be reduced if the expected traffic peak is less than 1.500 veh/h and lane. The allowed minimum lane width depends on the length of the work zone:

- Work zone length:
  - <6 km: 3.25 m – 2.5 m lanes only for passenger cars;
  - 6 to 9 km: 3.25 m - 2.5 m lanes only for passenger cars;
  - >9 km: 3.25 m.

The speed limit should be reduced to 60 km/h (in special cases to 40 km/h) if:

- the width of the lane for trucks is less than 3.25 m;
- the work zone is directly adjacent to the traffic zone;
- the road condition is bad;
- a longitudinal gradient of about 4.0% is present.

The maximum permissible speed can be set to 100 km/h if the width of the left temporary lane is at least 3 m and the right at least 3.5 m and if one of the conditions above occur. On the side to the adjacent working area, portable or permanent safety gear has to be installed.
German guideline (BMV, 2009) also state that the criteria grip at wetness, steadiness and road conditions must have a significant influence on the determination of the speed limits.

### 3.2.10 Switzerland

The Swiss Standards (SNV, 2007) allow a reduction of lanes width only if in the peak hour the traffic volume is less than 1 500 vehicles are on a lane for each direction (Table 3-7).

Table 3-7. Width Reduction as a Function of Speed Limit (SNV, 2007)

<table>
<thead>
<tr>
<th>Geschwindigkeitsbegrenzung</th>
<th>Fahrstreifenbreiten [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leerlauf</td>
<td>B1</td>
</tr>
<tr>
<td>Normalfall</td>
<td>100, ev. / év. 80</td>
</tr>
<tr>
<td>Minimum</td>
<td>80, ev. / év. 60</td>
</tr>
</tbody>
</table>

### 3.2.11 Italy

The Italian “Ministerial Decree 10 July 2002” (Italy, 2002) states that speed limit should be implemented in blocks (levels) of 20 km/h. The number of different signs or signals to be used will generally be at most three. In case of a speed reduction of 70 km/h (as an example, reducing the speed from 130 to 60 km/h in approach to a carriageway exchange on motorways) the third level of reduction will be increased to 30 km/h (110 - 90 - 60, Figure 3-6). In accordance with the criterion of credibility of the signals, the use of low speed reductions (5, 10 or 20 km/h) which are not actually justified by the conditions of the road surface or circulation particularly critical are to be avoided.

The choice of last maximum speed limit to be placed should considering the deviation angle for traffic and existing speed limits.

![Example of Speed Reduction in Italy (Italy, 2002)](image)

Figure 3-6. Example of Speed Reduction in Italy (Italy, 2002)

The Italian decree identifies three types of exchange:
The exchange of a single lane;
The exchange of two or more lanes;
Partial exchange.

Depending on the size of the opening in the barrier, a maximum speed limit at the point of exchange could be about 40 or 60 km/h. In that case a channelizing of the flow, upstream of the exchange, is preferable.

**England**

UK Guidelines (DFT, 2009) impose the following safety clearances:

- for all roads with a permanent speed limit of 80 km/h or more, the lateral clearance between the edge of the working space and that part of the carriageway being used by traffic should be not less than 1.2 m,
- if the nature of the road is such that a lateral safety clearance of 1.2 m cannot be achieved, then the lateral safety clearance should be as wide as practicable with an absolute minimum of 0.5 m, speed limits of 40 or 48 km/h will need to be put in place,
- on roads other than motorways, if there is insufficient space to provide the minimum lateral safety clearance of 0.5 m, there are a number of available options:
  - If practical, the road can be closed and traffic diverted along a suitable diversion route
  - If diversion of traffic would be impracticable, traffic speeds must be reduced to below 16 km/h and an agreed safe method of working imposed on the site; this must be agreed with the Highway Authority.
- For short lengths of work zones (50 m or less) on single carriageways, chicanes can be used. At least one chicane is required in each direction of the minimum size to allow a large vehicle to pass through slowly.

The longitudinal safety zone is defined as “an open or unoccupied space between the end of the lead-in taper and the working space and provides a margin of safety for both the traffic and the workers” (Figure 3-7).
It is important that the longitudinal safety zone is free of equipment, workers, materials and parked vehicles. The minimum longitudinal clearance should be based on the road’s permanent speed limit and not on any temporary reduced speed limit (Table 3-8). In Scotland, this requirement may be varied to the temporary speed limit with the agreement of Transport Scotland.

Table 3-8. Longitudinal clearances (DFT, 2009)

<table>
<thead>
<tr>
<th>Permanent speed limit (mph)</th>
<th>Minimum longitudinal clearance (m)</th>
<th>Desirable longitudinal clearance (m)</th>
<th>Minimum longitudinal exit clearance (m)</th>
<th>Desirable longitudinal exit clearance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 or less</td>
<td>0.5</td>
<td>10</td>
<td>0.5</td>
<td>9</td>
</tr>
<tr>
<td>40</td>
<td>15.0</td>
<td>30</td>
<td>3.0</td>
<td>9</td>
</tr>
<tr>
<td>50</td>
<td>30.0</td>
<td>50</td>
<td>3.0</td>
<td>9</td>
</tr>
<tr>
<td>60</td>
<td>60.0</td>
<td>100</td>
<td>9.0</td>
<td>9</td>
</tr>
<tr>
<td>70</td>
<td>100.0</td>
<td>200</td>
<td>9.0</td>
<td>9</td>
</tr>
</tbody>
</table>

The guidelines (DFT, 2009) use figures such as that in Figure 3-8 to provide criteria to define the crossover lengths for some commonly used layouts as a function of the temporary speed limit.
The length of the lane change section is also given as a function of the number of lanes to be changed and the original as well as work zone posted speed and an example is shown in Table 3-9.

Table 3-9: Changeover lengths (m) for Permanent Speed limit is 50 mph or more (DFT, 2009)

<table>
<thead>
<tr>
<th>Number of lanes changed</th>
<th>30mph</th>
<th>40mph</th>
<th>50mph</th>
<th>60mph</th>
<th>70mph</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>63</td>
<td>81</td>
<td>90</td>
<td>108</td>
<td>126</td>
</tr>
<tr>
<td>2</td>
<td>90</td>
<td>108</td>
<td>126</td>
<td>153</td>
<td>180</td>
</tr>
<tr>
<td>3</td>
<td>108</td>
<td>126</td>
<td>153</td>
<td>180</td>
<td>216</td>
</tr>
</tbody>
</table>

### 3.2.12 Czech Republic

Speed limits in work zones of Czech Republic are stated as follows (Czech, 2004):
- on highways the maximum permitted speed is 60 km/h;
- on other roads 40 km/h;
- for individual cases, for example when driving on bridges, work zone speed limits should be fixed at 30 km/h or less.

### 3.2.13 U.S.

On a national level, the American Manual of Uniform Traffic Control Devices (FHWA, 2009) sets out requirements and recommendations for protecting workers from oncoming or passing traffic, and road users from hazards within the site at a static worksite. The clearances to edge of work area are measured from the traffic-side edge of the line of delineating devices or barriers. It distinguishes the situations:

- Work area 6 m or more clear of traffic: If the entire work area including all vehicles and plant is located a minimum of 6 m from the nearest edge of a lane carrying traffic, no traffic delineation of the work area or temporary speed limit will be required but a Worker (symbolic) sign should be placed on the left side of the roadway in advance of the work area if workers or plant are visible to passing traffic.
• Work area 3 m to 6 m clear of traffic (Option 1 in Figure 3-9): If the entire work area including all vehicles and plant is located a minimum of 3 m from the nearest edge of a lane carrying traffic, no traffic delineation of the work area will be required but the following shall be provided:
  o A Worker (symbolic) sign in advance of the work area when workers or small items of plant are present on the site.
  o A vehicle mounted warning device.
  o In speed zones higher than 80 km/h, a temporary speed limit of 80 km/h where the traffic volume exceeds 10 000 vehicles per day.

• Work area closer than 3 m to traffic (Option 2 in Figure 3-9). If the work area is protected by a road safety barrier system, there will be no requirement to reduce traffic speeds for the protection of workers. Advance signing and delineation, including worker (symbolic) signs when workers are required, and temporary speed zoning may be required for the safety of traffic negotiating the site outside the barrier. Steps should be taken to ensure that workers and construction will remain within the protection of the barrier. A containment fence behind the barrier is recommended.

Figure 3-9. Safety Clearances: Between 3m to 6m and Less than 3m and (FHWA, 2009)

• Clearance to traffic between 1.2 m and 3 m (Option 3 in Figure 3-10). If there is no road safety barrier system between the edge of the work area and the nearest edge of a lane carrying traffic, but the clearance between the two is between 1.2 and 3 m, the following are required when workers or small construction equipment are on site (in addition to the requirements for other work site management devices specified in the standard):
  o A Workers sign in advance of the work area.
  o Delineation of the edge of the traffic lane by cones, bollards or similar.
  o Separate delineation of the edge of the work area by means of a containment fence if there is a risk of workers or small items of plant infringing the clearance area.
  o The speed of passing traffic shall be reduced to 60 km/h through the use of appropriate traffic control devices such as signs, flashing lights, traffic controllers and tapers (as approved by the State road authority). The alternatives could be imposing a temporary road work speed zone or a combination of the above. This last action is not required if the posted speed during road works past the site is already 60 km/h or less.

• Clearance to traffic less than 1.2 m (Option 4 in Figure 3-10): If the clearance requirement of 1.2 m shall apply all the requirements above except that the posted speed in the work
zone shall be reduced to 40 km/h using the methods already specified. Use of a containment fence may be omitted if there is insufficient space to place it.

Traffic controllers shall be allowed to operate only in an area where the posted speed during road works has been reduced to 60 km/h or less.

Figure 3-10. Safety Clearances: Between 1.2m to 3m and Below 1.2m and (FHWA, 2009)

Where any one or more of the following conditions apply at a static site, the posted speed during work zone activities shall be reduced to a value less than 40 km/h using the methods previously specified together with traffic controllers or pilot vehicles as needed:

- An unusually high hazard level for workers on foot within 1.2 m of moving traffic or other road users as a consequence of the work area.
- It is impracticable to separate pedestrians or cyclists from vehicular traffic in the work area.
- Construction does not involve any of the following:
  - Works being undertaken using large item of equipment exclusively.
  - Workers and road work delineation are separated from moving traffic by at least 1.2 m.
  - Grading or mowing on a median or verge which does not encroach onto a moving traffic lane.
  - Works on a residential street where the speed limit is 40 km/h or less.

FHWA (2009) states: “Reduced speed limits should be used only in the specific portion of the work zone traffic control where conditions or restrictive features are present” and that “Reduced regulatory speed limits should be avoided as much as practicable because drivers will reduce their speeds only if they clearly perceive a need to do so.”. The document specifies a minimum length of an 80 km/h temporary speed zone to be 500 m. A temporary 60 km/h speed zone shall be at least 150 m long. A temporary 40 km/h speed zone shall be no longer than 1 km and workers shall be visible. If traffic speeds are to be reduced by means of a temporary speed zone less than 40 km/h, the length of the zone shall not exceed 200 m and it should not be less than 100 m. Furthermore it defines particular conditions to be applied on temporary speed zones when one or more of the following conditions exist:
  - Loose material or stones are present on the road surface. (Speed limits should be removed after loose stone has been removed).
  - Sprayed seal works where higher speed may damage the new seal.
  - Dust or smoke may reduce visibility and cannot be controlled.
  - The standard of the pavement surface or the vertical or horizontal road geometry at a work site is reduced below that of the adjacent sections of road.
  - The unobstructed clear width of the roadway is substantially reduced.
  - Roadway surface is rough, uneven, gravel, or has abrupt edges.
3.2.13.1 US, Minnesota DOT
A guide provided by Minnesota DOT (Mn/DOT, 2002) states that speed limits are intended for use where the work area and workers are adjacent to travelled lane(s) open to vehicular traffic. This usually occurs in lane closures on multi-lane streets or highways. Work zone speed limits are not to be used on mobile or moving operations, bypasses or detours. Also, when flaggers are used to provide control on a lane closure on two-lane two-way streets or highways, work zone speed limits should not be used.

According the guide, as a general rule, the posted speed limit in the work zone should be 16 km/h (10 mph) below existing limit. On divided roads with established 112 km/h (70 mph) zones, the work zone speed limit must be dropped 24 km/h (15 mph) to be in compliance with the maximum 88 km/h (55 km/h). The work zone site should be test driven by the supervisor to confirm that the speed limit is set at a reasonable value for the activity being performed.

The guide states that the work zone speed limit must not reduce the established speed limit on the affected street or highway by more than 24 km/h (15 mph) and cannot be below 32 km/h (20 mph). On any divided highway, the maximum work zone speed limit shall not exceed 88 km/h (55 km/h). On other roads, the work zone speed limit shall not exceed 64 km/h (15 mph). The work zone speed limit shall be made effective upon erection of appropriate signs. The guide further states that the signs must be removed or covered or when they are not required.

3.2.13.2 US, Washington DOT
The WSDOT Traffic Manual (W/DOT, 2009) considers geometrical roadway factors to determine if a work zone speed limit reduction is needed. If traffic lanes are less than 3.35 m (11 ft) wide or shoulders are less than 1.22 m (4 ft), a reduction should be deployed. It considers these geometrical roadway factors together with the following conditions to determine if a work zone speed limit reduction is needed:

- Work zone is in a roadway section with more than two lanes in each direction.
- Work zone elements such as temporary road approaches, intersections, or intersection control (such as a temporary signal) have changed the roadway or roadside environment.
- Work zone has unusual or reduced roadway geometrics such as lane shifts, ramps, and acceleration/deceleration tapers.

The manual (W/DOT, 2009) states that when workers are exposed to live traffic, it should not be assumed that a lower speed limit will improve worker safety. Worker exposure to traffic should be reduced and traffic speeds should be controlled using the following effective safety strategies:

- Use of a pilot car for two lane paving operations to effectively control traffic speed past workers.
- Provide positive protection such as barriers and Truck Mounted Attenuators.
- Provide a lateral buffer space between workers and live traffic, defined by channelization devices, to allow space for minor traffic intrusions or occasional encroachment by workers. A half to full lane width is an acceptable lateral buffer for high speed conditions.
- Use closely spaced drums or tall channelizing devices to improve work area separation and motorist guidance.
- Additional warning devices such as temporary rumble strips, portable changeable message signs, or an automated flagger assistance device may improve flagger protection.

Furthermore when, in some case, such as a paving project on 96 km/h (60 mph) two lane highways, there are particular conditions, like:

- High worker exposure;
- Limited opportunities to use positive protection such as Temporary Concrete Barrier to protect workers and separate the work operation from traffic;
- Flaggers exposed to high speed traffic.
A variable regulatory speed limit reduction to 64 km/h (40 mph) for the duration of the work zone operation should be considered. The use of a pilot car operation will effectively control traffic speeds through the work zone. If a pilot car is used, a variable speed limit reduction may be unnecessary.

### 3.2.13.3 US, Michigan DOT

In Michigan (Mich/DOT, 2005) a specific state practice provides specific guidance for speed limits, depending on the position of the work zone:

- **Work activities, workers, materials, and equipment are at more than 4.57 m (15 ft) from the edge of the travelled way:**
  - No reduction of speed limit is required
  - There should not be a reduction to the regulatory speed limit, unless unusual situations create hazardous conditions for motorists, pedestrians, or workers. A temporary Traffic Control Order (TCO) is required prior to the start of work when speed reductions are required.

- **Work activities, workers, materials, and equipment that encroach on the area are closer than 4.57 m (15 ft) but not closer than 0.61 m (2 ft) to the edge of the travelled way:**
  1. **Speed Limits (where existing speed limits are 80 km/h (50 mph) or higher)**
     - Where workers are present with channelizing devices, a temporary speed limit of 72 km/h (45 mph) is required.
     - Where workers are present with concrete barriers, a maximum 16 km/h (10 mph) reduction or as geometric and physical conditions dictate.
     - If no workers are present a maximum 16 km/h (10 mph) reduction or as geometric and physical conditions mandate is required.

  **Speed Limits (where existing speed limits are 72 km/h (45 mph) or lower)**
  2. For all conditions a maximum of 16 km/h (10 mph) reduction or as geometric and physical conditions mandate.
     - No speed reductions are required where existing speed limits are 48 km/h (30 mph) or less.
     - Work activities, workers, materials, and equipment that encroach the area from within 0.61m (2 ft) of the edge of the travelled way to 0.61m (2 ft) into the lane from the edge of the travelled way: the speed limits are the same as the previous case with the only difference no traffic control order is required. Lane closures shall be required if the remaining lane is less than 3.05m (10 ft) in width, excluding the channelizing devices). In this case traffic control order is required.

Furthermore Michigan guidelines (Mich/DOT, 2005) provide factors for speed reductions during non-work periods or when barrier walls are present:

- For roadside activities:
  - Horizontal curvature that might increase vehicle encroachment rate (could include mainline curves, ramps, and turning roadways).

- For lane encroachment:
  - Horizontal curvature that might increase vehicle encroachment rate (could include mainline curves, ramps, or turning roadways).
  - Barrier or pavement edge drop-off within 0.61m (2 ft) of travelled way.
  - Reduction in sight distance.

However Michigan state practice doesn’t apply any speed limit reduction for short duration work zones or mobile activities on the shoulder.

### 3.2.13.4 US, New York DOT

Engineering Instruction (NYDOT, 2008) provided by the New York State Department of Transportation recommend that advisory or regulatory speed limit reductions in work zones are to
be established consistent with changes in the physical character of the work area. In long work zones with many intermittent activity areas, where it has been determined that a regulatory speed limit reduction is necessary at each activity area, the preconstruction posted speed limit shall be restored between activity areas where they are separated by 3 km or greater. Following this instruction a regulatory speed limit reduction shouldn’t be implemented for mobile work zones or short duration (up to 1 hour) work activities. In cases of short term stationary work zones (more than 1 hour and maximum 3 consecutive days shift), if the work zone is classified as “major active” and length of the activity area is major than 0.5 miles (804.67 m), a regulatory speed reduction of 16 km/h (10 mph) should be implemented. A “major active work zone” has the following conditions:

- Work on fully controlled access roadway with preconstruction posted speed limit of 88 km/h (55 mph) or greater;
- Workers on foot on the roadway are not predominantly separated from traffic by positive protection such as temporary concrete barrier.

In long term work zone activities (more than 3 consecutive days) the speed limit choice depends on the presence of a geometric transition (change in the existing horizontal or vertical alignment of the travel lane) through the work zone. Lane shift or lane closure are not considered a geometric transition when appropriate taper lengths are provided. If the transition is a freeway median crossover that results in opposing traffic and the posted speed limit is higher than 104 km/h (65 km/h), a regulatory speed reduction is recommended. Otherwise, the length of the activity area is evaluated to determine if the reduction in regulatory speed is necessary. Any speed limit reduction should not be more than 16 km/h (10 mph) below the preconstruction posted speed limit unless an engineering study shows that geometric conditions warrant a greater speed limit reduction.

### 3.2.14 Canada

#### 3.2.14.1 Quebec

Legislation of Quebec (Quebec/DOT, 2008) requires a maximum speed limit reduction of 30 km/h for roads with a permanent speed limit higher than 50 km/h and a maximum reduction of 20 km/h for roads with a permanent speed limit lower than 50 km/h. The choice of the temporary speed limit depends on the number of lanes closed to traffic and the presence of road workers. A 10 km/h reduction (compared to the permanent speed limit) is required per obstructed lane.

The legislation (Quebec/DOT, 2008) requires an additional 10 km/h reduction when the work zone is not protected by any temporary vehicle restraint system and allows, for particular circumstances (e.g. due to laying concrete on a bridge), speed reductions higher than 30 km/h if appropriate measures are not taken to ensure the temporary speed limit is respected.

#### 3.2.15 Australia

##### 3.2.15.1 Australia, New South Wales

The New South Wales Government (NSW, 2010) states that the posted speed in work zones shall be reduced to a value less than 40 km/h where one or more of the following conditions apply at a static site:

- An unusually high level of hazard for workers on foot within 1.2 m of the moving traffic with no intervening physical barriers;
- It is impracticable to separate pedestrians or cyclists from vehicular traffic in the work area;
- Workers and road work delineation are separated from moving traffic by less than 1.2m;
- Grading or mowing on a median or verge which encroach onto a moving traffic lane;
- Works on a residential street where the speed limit is more than 40 km/h.

Furthermore (NSW, 2010) requires a reduced speed limit up to 60 km/h if a traffic controller is inside the activity area and states that 40 km/h and 60 km/h work zone speed limits shall be
located so that the zone begins no closer than 100m before the start of the work, which is the start of transition area or traffic diversion or the traffic control position. The roadwork speed zone shall end at least 50 m past the site where people are working.

The desirable lengths of work zone speed zones are divided as follows (Table 3-10):

<table>
<thead>
<tr>
<th>Speed Limit</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 km/h</td>
<td>not specified</td>
<td>500m</td>
</tr>
<tr>
<td>60 km/h</td>
<td>150m</td>
<td>not specified</td>
</tr>
<tr>
<td>80 km/h</td>
<td>500m</td>
<td>not specified</td>
</tr>
<tr>
<td>80 km/h</td>
<td>300m</td>
<td>not specified</td>
</tr>
</tbody>
</table>

In general there is no maximum length specified but, for traffic safety, speed management devices shall be considered.

(NSW, 2010) requires that the speed of traffic passing through a work zones should be reduced to 60 km/h if the following conditions occur:

- Presence of reduced standard of alignment due to the works;
- There is a loose surface such as gravel or newly sprayed bitumen seal;
- Dust or smoke reduce visibility;
- Traffic is adjacent to an excavation.

The posted speed limit should be further reduced to 40 km/h if a severe change in the alignment, considering the surrounding environment, occurs or in case of works zones on bridges where the deck has an inconsistent surface or there might be structural damages to the bridge by vehicles travelling at higher speeds. If the project manager determines that the impact loading caused by traffic threatens the structural safety of the bridge the temporary speed limit may be lower than 40 km/h.

3.2.15.2 Australia, Queensland

According to Queensland requirements and recommendations (Queensland, 2009), the clearance to edge of work area is a key factor for safety management and setting speed limits. If the entire work area including all vehicles and equipment is located a minimum of 6 m from the nearest edge of a lane carrying traffic, no traffic delineation of the work area or temporary speed limit will be required. If the entire work area including all vehicles and plants is located a minimum of 3 m from the nearest edge of a lane carrying traffic, no traffic delineation of the work area will be required but the following shall be provided:

- In speed zones with a general speed limit higher than 80 km/h, a temporary speed limit of 80 km/h is to be adopted where the traffic volume exceeds 10 000 vpd.

If the clearance between the work area and the nearest edge of a lane carrying traffic is less than 3 m the following options shall be used:

- Protection by road safety barrier system: If the work area is protected by a road safety barrier system, there will be no requirement to reduce traffic speeds for the protection of workers;
If there is no road safety barrier system between the edge of the work area and the nearest edge of a lane carrying traffic, but the clearance between the two is from 1.2 m to less than 3 m, the following are required when workers or small items of equipment are on site:
- a worker’s (symbolic) sign in advance of the work area;
- delineation of the edge of the traffic lane by cones, bollards or similar means,
- separate delineation of the edge of the work area by means of a containment fence if there is a risk of workers or small items of plant infringing the clearance area.
- the speed of passing traffic shall be reduced to 60 km/h through the use of appropriate traffic control devices such as signs, flashing lights, traffic controllers and tapers. A temporary 60 km/h speed zone shall be at least 150 m long.

If the clearance requirement of 1.2 m cannot be achieved, all of the requirements above shall apply except that the posted speed in the work zone shall be reduced to 40 km/h using the methods specified. A temporary 40 km/h speed zone shall be no longer than 1 km and workers shall be visible.

For short-term and low impact works in built-up areas, lighter treatments (without any temporary speed limit) are permitted for:
- frequently changing work area in which the work is not within traffic lane and provided (amongst other) that the speed limit is 70 km/h or less;
- frequently changing work area in which the work is within traffic lane but speed limit is 60 km/h or less;
- works on medians, verges and footpaths.

Where there are no workers on foot, the following relationship between speed limit and clearance to edge of traffic lane apply:
- speed limit of 90 km/h or more when the clearance is greater than 1.2 m;
- speed limit of 80 km/h or less when the clearance is less than 1.2 m but plant items do not encroach onto the traffic lane.

Where there are workers on foot or small items of plant, or both, the following restrictions apply:
- The speed limit is 60 km/h or less and the work area does not encroach onto a moving traffic lane.
- The speed limit is 80 km/h or less and the clearance to edge of traffic lane is at least 1.2 m;
- The entire work area is at least 3 m clear of a moving traffic lane.

### 3.3 Signalling

#### 3.3.1 Belgium

The Belgian decree of May 7th, 1999 (Belgium, 1999) defines the distances of the advanced warning speed limits from the beginning zone of the work activity on the basis of the impact on traffic flow, the type of road, the posted speed limit and the entity of the width reduction of the lanes open to traffic. For category 1 road works (see definition in the previous chapter) having a severe impact on traffic flow it requires:
- On motorways (posted speed limit of 120 km/h):
  - Advanced Warning Speed limit: 90 km/h (at -1100 m from the activity area) followed by 70 km/h (-500m & -150m; or 50km/h following the local condition needs).
- On other roads (posted speed limit between 90 and 120 km/h):
  - Advanced Warning Speed limit: 90 km/h (between -750m & -550m) followed by 70km/h (between -550m & -350m; or 50km/h following the local condition needs).

For category 1 road works having a moderate impact on traffic flow:
- On motorways (posted speed limit of 120 km/h):
• With a width reduction of the lanes open to traffic: Advanced Warning Speed limit: 90 km/h (-400m & -150m; or 70km/h following the local condition needs).
• Without any width reduction of the lanes open to traffic: No Advanced Warning Speed limit proposed.
• On other roads (posted speed limit between 90 and 120 km/h):
  • With a width reduction of the lanes open to traffic: Advanced Warning Speed limit: 90 km/h (-350m & -150m; or 70km/h following the local condition needs).
  • Without any width reduction of the lanes open to traffic: No Advanced Warning Speed limit proposed.

The standard tender specifications used in Wallonia (WRA, 2013) requires that for all road works speed limit signs must be repeated every 500m for short work zones (less than 2km) and every km for longer road works (longer than 2km).

The standard tender specifications used in Flanders (FRA, 2012) specifies that for category 6 road works (defined as mobile road works hindering the traffic due to their low speed of frequent stops) executed on a trafficked lane or shoulder lane of motorways and roads with a posted speed limit above 90 km/h should be announced with permanent dynamic signs or variable Message Signs (VMS) and the speed limit must be reduced up to 90km/h. The speed reduction must be announced upwards or preceded by a 110 km/h or 100 km/h speed limit.

3.3.2 Norway
The Norwegian guidelines (Hague et al, 2012) state that temporary speed limits at work zones shall be repeated at a maximum of 250 m apart, and after each intersection. Furthermore they provide minimum requirements for a clear view of the temporary road traffic signs as a function of speed limit. Sign size depends on the posted speed limit. When the speed limit sign is used for temporary regulation it may have a yellow background. Since temporary speed limits usually reduce the road capacity, the time interval between vehicles in the same direction is estimated for different speed limits. Maximum distances between longitudinal warnings and recommended distance between speed reducing devices for different speed levels are defined.

3.3.3 Denmark
The Danish handbook (Vejdirektoratet, 2012) stipulates at least 2 seconds driving time between two message signs to allow time to read and understand the message. Minimum distances between two message signs versus speed limit are given in Table 3-11. The minimum distance between speed limit signs when the speed limit is reduced is given in Table 3-12.
Table 3-11. Minimum distance between two message signs (Vejdirektoratet, 2012)

<table>
<thead>
<tr>
<th>Speed limit (km/h)</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum distance between two message signs</td>
<td>23 m</td>
<td>28 m</td>
<td>34 m</td>
<td>39 m</td>
<td>45 m</td>
<td>50 m</td>
</tr>
</tbody>
</table>

Table 3-12. Minimum distance between two consecutive speed limit signs (Vejdirektoratet, 2012)

<table>
<thead>
<tr>
<th>Consecutive speed limit signals</th>
<th>130–110</th>
<th>110–80</th>
<th>80–50</th>
<th>60–50</th>
<th>50–40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum distance between two consecutive speed limit signs</td>
<td>154 m</td>
<td>183 m</td>
<td>125 m</td>
<td>35 m</td>
<td>29 m</td>
</tr>
</tbody>
</table>

Depending on the speed limit, the type of road (motorways or others roads) and the road environment (road exit, no edge line, etc.) distances between cones is given in Table 3-13.

Table 3-13. Distance between cones (Vejdirektoratet, 2012)

<table>
<thead>
<tr>
<th>Road type</th>
<th>Road environment</th>
<th>Speed limit</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorway</td>
<td>No edge line</td>
<td>50–80 km/h</td>
<td>10 m</td>
</tr>
<tr>
<td></td>
<td>Along workzone</td>
<td>80–110 km/h</td>
<td>30 m</td>
</tr>
<tr>
<td></td>
<td>At closed exits</td>
<td>All</td>
<td>5 m</td>
</tr>
<tr>
<td>Other roads</td>
<td>Along workzone</td>
<td>All</td>
<td>15 m</td>
</tr>
<tr>
<td></td>
<td>Next to cycle lane and pavement</td>
<td>All</td>
<td>3 m</td>
</tr>
</tbody>
</table>

3.3.4 Italy
The Italian “Ministerial decree 10 July 2002” (Italy, 2002) states that users should always know why the speed is limited. Therefore, the sign “speed limit” should never be the first sign encountered by the user and therefore should be placed after a “warning sign”. The "speed limit" sign must be repeated each time the affected road segment is longer than 1.0 km. After the work zone ends an "End speed limit" or "End of all Restrictions" sign needs to be placed.

3.3.5 England
UK guidelines (DFT, 2009) define the following distances of the first sign to the work zone, as a function of the permanent speed limit on the single carriageway road (Table 3-14):

...
Table 3-14. Distances of the first sign to the work zone (DFT, 2009)

<table>
<thead>
<tr>
<th>Single carriageway road: Permanent speed limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>30mph or less</td>
</tr>
<tr>
<td>Minimum and normal maximum sitting distance D of first sign in advance of lead-in taper in metres</td>
</tr>
<tr>
<td>Minimum longitudinal clearance L in metres¹</td>
</tr>
<tr>
<td>Length of taper T in metres⁷:</td>
</tr>
<tr>
<td>Width of hazard (metres) including safety zone S</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Minimum lateral safety zone clearance</td>
</tr>
<tr>
<td>Distance E to “end of work zone” sign</td>
</tr>
</tbody>
</table>

3.3.6 Austria
The Austrian ASFiNAG’s guide for traffic management and traffic safety in work zones (FSV, 2012) states that warning signs can be omitted in short-term construction sites.

3.3.7 US

3.3.7.1 US, Minnesota DOT
A guide published by Minnesota DOT (Mn/DOT, 2002) defines the following sizes for different signs, in function of the posted speed limit (Table 3-15).

Table 3-15. Signs Size (Mn/DOT, 2002)

<table>
<thead>
<tr>
<th>MINIMUM SIGN SIZES FOR TEMPORARY SPEED LIMITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIGN</td>
</tr>
<tr>
<td>POSTED SPEED LIMIT PRIOR TO WORK STARTING</td>
</tr>
<tr>
<td>0-64 km/h</td>
</tr>
<tr>
<td>SPEED LIMIT SIGN</td>
</tr>
<tr>
<td>REDUCED SPEED AHEAD</td>
</tr>
<tr>
<td>END WORK SPEED ZONE</td>
</tr>
<tr>
<td>FINES DOUBLE</td>
</tr>
</tbody>
</table>

In Table 3-16 and Table 3-17, the spacing distances between warning signs and speed limit signs as a function of speed limits are shown.
Table 3-16. Spacing between Advance Warning Signs (Mn/DOT, 2002)

<table>
<thead>
<tr>
<th>Posted Speed limit prior to work starting</th>
<th>Spacing of Advance Warning Signs</th>
</tr>
</thead>
<tbody>
<tr>
<td>km/h</td>
<td>meters</td>
</tr>
<tr>
<td>0-48</td>
<td>80</td>
</tr>
<tr>
<td>56-64</td>
<td>100</td>
</tr>
<tr>
<td>72-80</td>
<td>180</td>
</tr>
<tr>
<td>89</td>
<td>230</td>
</tr>
<tr>
<td>97-105</td>
<td>300</td>
</tr>
<tr>
<td>113-121</td>
<td>370</td>
</tr>
</tbody>
</table>

Table 3-17. Spacing between Speed Limit Signs (Mn/DOT, 2002)

<table>
<thead>
<tr>
<th>Temporary Speed Limit</th>
<th>Speed limit Sign Spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>km/h</td>
<td>meters</td>
</tr>
<tr>
<td>32 - 40</td>
<td>400</td>
</tr>
<tr>
<td>48 - 56</td>
<td>800</td>
</tr>
<tr>
<td>64 - 72</td>
<td>1200</td>
</tr>
<tr>
<td>80 - 121</td>
<td>1600</td>
</tr>
</tbody>
</table>

All regulatory speed limit signs consist of black legend on white reflecting background. The "FINES DOUBLE" plaque consists of a black legend on reflecting orange background and should be the same width as the speed limit sign. The plaque should be mounted above the speed limit sign. Applications on higher volume and higher speed roadways, such as freeways and expressways, should use larger signs to provide for adequate target value and legibility.

When the work zone speed limit calls for a reduced speed that results in a difference of 24 km/h (15 km/h) from the preceding zone, then a "REDUCED SPEED AHEAD" sign should be used. The sign is not required for reductions of 8 - 16 km/h (5-10 mph) but may be used. When this sign is posted with the temporary mounted advance warning sign series, it must be mounted at least one foot above the pavement. If the advance warning series is mounted on post driven structures or attached to other fixtures, all signs should be mounted at the same height. If the work zone speed limit is not in effect then the "REDUCED SPEED AHEAD" sign should be covered or removed. The signs should be placed in the shoulder or ditch area on the side of the road open to thru traffic. Signs should not be erected in the closed lane since equipment and channelling devices may obstruct visibility of the signs.

The guide (Mn/DOT, 2002) requires that speed limit signs shall only be posted in the traffic control zone during continuous worker activity while performing construction or maintenance operations. Overuse of the work zone speed limit will reduce the effectiveness; therefore, these must be
prudently applied only where the motorist can perceive the need to reduce speeds. During periods of no activity or when the traffic controls are removed from the roadway, the speed limit signs shall be covered or removed. This means installing signs at the beginning of a work shift and removing signs at the end of the shift.

3.3.7.2 US, Washington DOT
WSDOT (W/DOT, 2009) highlight that driver confusion can be avoided or reduced through the use of enhanced guidance and information. Driver performance is improved by providing concise and accurate messages and visual cues that show the work zone conditions and travel path. Electronic driver feedback signs and occasional enforcement may be used to reinforce the existing speed limit and minimize any traffic speed differential.

3.3.7.3 US, New York DOT
Engineering Instruction (NYDOT, 2008) provided by the New York State DOT states that when traffic is open for only a single lane of traffic, the speed limit sign setup shall be posted on the right hand side of the roadway only. For multiple lanes of traffic open to traffic the sign should be posted both sides.

3.3.8 Australia,

3.3.8.1 Queensland
Following Queensland legislation (Queensland, 2009) if the entire work area including all vehicles and equipment is located a minimum of 3 m from the nearest edge of a lane carrying traffic, no traffic delineation of the work area will be required but shall be provided a worker (symbolic) sign in advance of the work area when workers or small items of plant are present on the site and vehicle mounted warning device.

3.4 Traffic Control Measures
Many speed management criteria can be deployed in order to increase the compliance to temporary speed limit through the work zone. Experience with different techniques are provided in the following discussion.

3.4.1 Sweden
Swedish standards suggest (Trafikverket, 2010, Trafikverket, 2012a) that speed through a road work site can be reduced by using optical and physical devices. The effect of the physical devices (the actual speed reduction) must correspond to the current speed limit or recommended speed. Traffic calming measures to be used could be, as an example, narrowing lanes, road humps, "active speed barriers", the buffer grooves chicane (S-curves of small radius), and lateral movement of the traffic.

3.4.2 Norway
Additional speed reducing measures shall be used if the average speed is higher than the speed limit or if the 85% percentile is higher than 5 km/h above speed (Hauge et al, 2012). Recommended speed reducing measures are clear speed limit signs, 'port', s-bend, visual narrowing and speed humps.
3.4.3 Denmark
The Danish handbook (Vejdirektoratet, 2012) recommends the use of Variable Message Signs for temporary speed limits in case of dense traffic, congestion, conflicts at dangerous crossings, and cyclists at dangerous crossings, working traffic, or people on the road. The sign ‘Your speed XX km/h’ can only be used if the speed limit is not greater than 80 km/h. Temporary traffic lights can only be used if the speed limit is not greater than 70 km/h. If the mean speed level is higher than the speed limit or if in case of the 85th percentile is 10 km/h higher than the speed limit, a failure to comply exists and speed reducing measures should be introduced, such as speed control, warning sign ‘people on the road’, speed bump (speed limit ≤ 50), rumble strips, speed reducing offsets, port, sign ‘Your speed XX km/h’ and alternately one-way traffic.

3.4.4 England
UK Guidelines (DFT, 2009) state that the designer should involve enforcement agencies early in the design of a road work scheme to ensure agreement on enforcement issues and the siting of cameras and signs. The locations of cameras, either for fixed point or average speed measurements, should be selected to reduce the likelihood of drivers making sharp braking manoeuvres. The factors affecting the choice of traffic control methods are summarised in Table 3-18.

Table 3-18. Traffic control methods in the UK (DFT, 2009)

<table>
<thead>
<tr>
<th>Method</th>
<th>Maximum speed limit (mph)</th>
<th>Length of coned area (max)</th>
<th>Maximum traffic flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Give and take”</td>
<td>30</td>
<td>50 m</td>
<td>400 veh/hr and 200KG/yr</td>
</tr>
<tr>
<td>Priority signs</td>
<td>60</td>
<td>80 m</td>
<td>840 veh/hr</td>
</tr>
<tr>
<td>“STOP/GO” signs</td>
<td>60</td>
<td>100 m</td>
<td>1400 veh/hr</td>
</tr>
<tr>
<td></td>
<td></td>
<td>200 m</td>
<td>1250 veh/hr</td>
</tr>
<tr>
<td></td>
<td></td>
<td>300 m</td>
<td>1060 veh/hr</td>
</tr>
<tr>
<td></td>
<td></td>
<td>400 m</td>
<td>940 veh/hr</td>
</tr>
<tr>
<td></td>
<td></td>
<td>500 m</td>
<td>840 veh/hr</td>
</tr>
<tr>
<td>Portable traffic signals</td>
<td>60</td>
<td>300 m (max)</td>
<td>No limit</td>
</tr>
<tr>
<td>“STOP-WORKS”</td>
<td>60</td>
<td>Not applicable</td>
<td>Not applicable</td>
</tr>
</tbody>
</table>

3.4.5 U.S.
The American MUTCD (FHWA, 2009) recommend the use of appropriate traffic control devices such as signs, flashing lights, traffic controllers and tapers (as approved by the State road authority), or a combination of them, when a speed reduction has to be adopted.

3.4.5.1 US, Washington DOT
The WSDOT Traffic Manual (W/DOT, 2009) considers that, when workers are exposed to live traffic, it shouldn’t be assumed that a lower speed will improve worker’s safety. Traffic speeds should be enforced with, for example, additional warning devices such as temporary rumble strips, portable changeable message signs, or an automated flagger assistance device to improve flagger protection.
### 3.4.6 Australia,

#### 3.4.6.1 Australia, Queensland
Following Queensland legislation (Queensland, 2009) temporary speed zones to be implemented for traffic safety purposes are appropriate where the consequences of excessive speed are not apparent and motorists are therefore unlikely to reduce speed voluntarily. A speed zone should not be introduced unless it is either self-enforcing or will be enforced.

The Speed Restriction sign shall be used to create a temporary speed zone. It indicates the speed limit which applies between the sign and the next speed control sign ahead. A variable speed limit sign may be used. Repeater Speed Restriction signs may be erected at intermediate locations within the zone. The end of a temporary speed zone shall be indicated by a Speed Restriction sign displaying the appropriate speed limit for the road continuing beyond the works or the “END Speed Limit” sign.

### 3.5 Evaluation of the Different Criteria

Selecting a work zone speed limit has several elements that need to be considered. To avoid linking work specific activities (i.e. paving, painting, excavating, etc.) to the speed requirements, variables that could be linked directly to the traffic management system were investigated. The main factors identified were:

- Original posted speed limit
- Type of road
- Impact on traffic flow
- Reduction of lane widths in the work zone
- Presence of workers
- Proximity of workers to the traffic passing
- Changes in road surface properties
- Presence of crossovers and changeovers
- Duration of road works

There is a fairly common theme in the national guidelines that speed reductions in work zones should be avoided if possible. As identified by Migletz, et. al. (1998), there is little gain in safety for large speed limit reductions. Ideally, work zones should be arranged to intrude as little as possible on normal traffic. When lowered speed limits are required there were some areas in common in the countries but the level of details differs among the countries and regions.

A general summary of the nine different factors used to define work zone speed limits is provided in Table 3-19 for the guidelines reviewed. An “X” indicates explicit use of the factor in setting speed limits. In general all countries are using normal speed limit and/or road type as an important factor for work zone designs. Similarly, the presence of workers, their proximity to traffic, and the duration or physical length of the work zone is also relevant for assigning work zone speeds.

Many documents mentioned that speed limit changes should be avoided when there is no activity in the work zone or if the work zone is long, because the driver tends to get impatient. Several references were made to driver irritation or impatience for longer work zone.

Reductions in lane widths and associated speed reductions were not described in all documents but tables linking maximum speeds for associated lane widths were reported by some countries.

Many standards state that minimum lateral and longitudinal clearances should be provided between moving traffic and the works for different types of roads. Within this safety zone, workers
and equipment should not enter in the normal course of work and materials should not be deposited in order to ensure safety during road works.

In general road work zones should be designed to minimize the risks to road users and to the workforce. Safe systems of work at road works are achieved by the provision of safety zones around the work areas using appropriate signage and delineation methods. In certain circumstances, it may also be beneficial to introduce a temporary speed restriction to further reduce the risks.

Some guidelines state that where, due to the presence of the work zone, the traffic is crossing the central reserve, and additional speed reductions should be implemented. The amount of reduction will depend on the length of the crossing area and on the number of lane changes.

The presence of reduced standard of road alignment due to the construction and change in road surface properties can represent other important criteria for reducing speed limit: a rough, uneven, gravel or slippery surface requires a temporary lowering of the speed limit. Also friction due to wetness and steadiness of the vehicles should be evaluated.

<table>
<thead>
<tr>
<th>Original Posted Speed</th>
<th>Road Type</th>
<th>Lane Width</th>
<th>Duration or Length of Construction</th>
<th>Workers Present</th>
<th>Proximity of Workers to Traffic</th>
<th>Impact on Traffic</th>
<th>Changeovers and Crossovers</th>
<th>Change in Road Surface Properties</th>
</tr>
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<tr>
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<td>x</td>
<td>x</td>
<td>x</td>
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<td>x</td>
<td>x</td>
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<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

Other less relevant criteria for reducing speed limits have also been found in the review:

- Use of temporary vehicle restraint system (or not);
- Loose material or stones on the road;
● Dust or smoke when they reduce visibility;
● Traffic adjacent to an excavation;
● Work zone on bridges;
● Heavy objects (rock crags, construction machinery, structures) dangerous to collide in case of driving off the road.
● Depth of construction pits

Although there are some common factors used by different countries to assign work zone speed limits, there is a great deal of variation in how the factors are used to define speed limits. While some countries have documents describing small speed reductions (in line with the Migletz (1998) results), there are still other countries describing multiple levels of 20 km/h speed reductions or 30 km/h steps. Another issue with the existing guidelines is that many speed limits are not automatically assigned but are based on the judgment of the analyst. Many documents refer to subjective interpretation of the conditions and there is no easily identified monograph, flowchart, or similar objective procedure that can objectively determine appropriate speed limits. Further analysis with actual speed and safety data is needed to determine if any uniform work zone speed limit management criteria can be derived in a generic guideline for Europe.

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4 METHODS USED TO MANAGE AND CONTROL THE SPEED OF VEHICLES IN ROAD WORK ZONES

4.1 Introduction

Several speed control techniques are currently used worldwide to improve speed limit compliance. This section of the report provides a detailed review of safety measures used to improve compliance with speed limits in road work zones. These safety measures can be categorised based on their functional characteristics as Informational, Physical and Enforcement measures. The main aim of this section is to develop a synthesis of practices on work zone speed management.

The frequency of maintenance activities and the potential severity of work zone accidents have intensified the importance of safety in work zones. Most studies found an increase in the risk of a crash or the number of crashes at work zones but the accompanying crash severity seems to be lower than other crashes. With regard to the crash types, rear-end collisions are the most common at work zones on higher speed roads (such as national roads and motorways) and are also more common than at locations where there are no road work underway. On urban roads, side collisions are the most common.

Speeding is the most frequently mentioned cause of crashes in work zone situations. In most cases the direct relation between crashes and work zones is unclear. However the relationships between travel speed and accident rates indicate that accident rates increase as speed variance increases (Gadiraju, R., 1998). A large speed variance coupled with hazardous conditions at work zones (e.g., workers’ presence, lane closure, and narrow lane) may lead to higher accident rates at work zones.

4.2 Informational Measures

On method to address appropriate speed limits is to provide motorists with information related to work zones, speed limits, penalties for traffic law violation, real-time speed feedback of individual motorists, and hazard warnings. The measures commonly adopted in this area are:

- Regulatory speed limit signs;
- Speed monitoring displays;
- Changeable message signs;
- Flaggers.

4.2.1 Regulatory speed limit signs

Posted speed limit reductions in work zones are the primary means of advising drivers that a reduced speed is either in effect or is advisable and also provide the legal basis for enforcement. Alternatively, advisory speed limit signs indicate a recommended safe speed through temporary work zones. Advisory speed limit signs are generally used as supplementary warnings of an approaching hazard.

The solution to work zone speed management is not simply posting low speed limits. It has generally been found that control of traffic speeds by imposing unwarranted regulatory speed limits has not been very effective. It is the situation they see and not the reduced speed limit that cause drivers to reduce their speeds (FHWA, 2011). Two factors should be taken into consideration on drivers’ speed choice:
• **voluntary reduction**: is lower than 16 km/h (10 mph in US studies), often closer to 8 km/h (unless the presence of enforcement) and is due to the presence of devices or to the assertion from authorities to reduce speeds.

• **involuntary reduction**: depends on “what the driver sees” in their field of view. The driver slows down only if there is the perceived need to do so. This is based on conditions in the work zone or the perception of enforcement activities. Typically the drivers slow down when large equipment and work crews are located close to the travelled way, when a roadway restriction occurs (temporary crossovers or narrowed lanes) or temporary traffic barriers are near to the edge of the lane.

An effective measure to improve “speed behaviour” (compliance to speed limits) is to increase the credibility of speed limits. It is assumed that when speed limits are more credible, the speed limit is in line with the expectations; drivers are better inclined to comply with them (SWOV, 2012). Advisory speed plaques and supplement warning signs should therefore be considered before deciding to lower the speed limit. If drivers do not perceive a hazard, they will not reduce their speeds. Similarly, if the advisory speed seems excessively low, drivers will not slow down to that speed. Of greater concern, they will lose confidence in other signs where the speed may be realistically posted, thus failing to adhere to the advisory speed where it is particularly important to do so. When the speed limits are credible a positive effect is expected on average driving speeds or speeding and on homogeneity of the traffic flow. When speed limits are less credible, some drivers will comply but others make their own decision on what speed they consider reasonable on that road which may lead to larger speed differences.

Most of the national standards state the work zone speed limit reductions should be avoided, when possible, where all work activities are located on shoulder or roadside areas and in work zones and where no work activities are under way. In general a basic guideline to follow is to attempt to reduce speeds only if there is a good reason for it.

Several research studies show that it is difficult to achieve an average speed reduction of more than 15 km/h. Posted speed limits in work zones should not be more than 20 km/h below the normal posted speed limit for that road section, except where required by restricted geometries or other work zone features that cannot be modified. It should be noted that some standards (e.g. in Austria, Belgium) require a very consistent speed reduction (50 km/h on motorways) on any work zone.

Experience has shown that the use of signs to reduce the speed of traffic through work zones has varying degrees of effectiveness. A study conducted by Colorado DOT (Outcalt, 2009) has shown that long-term work zones with significant speed reductions and where workers and equipment are far from traffic tend to make drivers doubt the credibility of the posted speed limit. This work showed that drivers reduce speeds in work zones, particularly when workers are present, independently of whether or not speed limit reductions are posted. Speed reductions should be carefully evaluated, and work zone speed limits should be set no lower than necessary and imposed no longer than necessary.

Within the Nordic Road Association (NVF), the committee for pavements (NVF 33) studied the safety of people working with pavement construction and maintenance on roads. National workgroups studied accident statistics, laws, rules and best practice, and summarized their results by country (Kalman, & Sjöholm, 2010). The status report from the Finnish workgroup states that speeding occurs, among other situations, when the stretch with temporary speed reduction is much longer than the actual work area, which is the case in hot weather when the risk of deformation of the new road surface increases.

A project performed in cooperation between the Texas Department of Transportation and the Federal Highway Administration recommended an 8 km/h (5 mph) maximum speed reduction for shoulder activity and lane encroachment conditions (Finley et al, 2008). A 16 km/h (10 mph)
maximum speed reduction is still warranted for lane closures and temporary diversions. Speed limit reductions should be discouraged on roadways with existing speed limits less than 104 km/h (65 mph) for all conditions except in case of lane closures when workers are in a closed lane which is not physically protected by a barrier and only a single travel lane remains open. Short term work zone speed limits are posted only when work activity is present. When the work activity is not present, the short term work zone speed limit signs should be removed or covered.

A survey, conducted by the Center for Transportation Research and Education (CTRE), shows that out of the 34 agencies that responded, 28 agencies included the use of regulatory speed signs among the strategies employed at their work zones (Maze et al, 2000). Only two agencies indicated that posting regulatory speed signs is effective in reducing work zone speeds. Ten agencies indicated that the use of regulatory signs is partially effective with estimated 30–50 % speed limit compliance. Moreover, the North Dakota DOT reported that posting a 32 km/h (20 mph) speed reduction below regulatory signs is ineffective. The policy of reducing speed limits by 16 km/h (10 mph) below the normal posted speed seems slightly more effective.

The NCHRP Research Results Digest 192 included a comprehensive literature review on the use of regulatory speed signs. This review determined that for a few studies, these signs were quite effective, but most of them showed that they have a negligible effect on vehicle speeds. However, the result that drivers are more likely to exceed the speed limit in a work zone with a high speed limit reduction as reported by several previous studies was not found in a study by University of Missouri-Columbia (Hou et al, 2011). In this study, conducted on three Interstate maintenance short-term work zones in Missouri the percentage of speeding was almost halved using speed limit reductions from 0 to 16 km/h (10 mph). When the speed limit was further reduced by another 16 km/h (10 mph), the percentage of speeding was reduced to about one fifth of the percentage reported in the base condition with no speed limit reduction.

The accident data collected by Lyles (Lyles et al, 2004) did not show a large difference in the average number of accidents at locations where the speed limit was increased or decreased. Their study recommends that the 85th-percentile speed should be used as the standard method to establish speed limits. There are some conditions in which the speed limit should be varied over time and static speed limits cannot effectively account for these variations. They found the variable speed limit (VSL) displays which change with changing conditions and impose more credible limits on motorists. The same study showed that static speed limit signs have less credibility than the VSL and variable message sign (VMS) systems.

In general Variable Speed Limits have more influence on speed reduction than traditional static signs (Figure 4-1).
Variable Speed Limits can be used to alter the speed limit considering the on-going conditions in the work zone (e.g., as workers are present or weather deteriorates) posting a reasonable speed limit, based on real-time traffic flow, roadway and speed conditions.

In U.S. the Intelligent Transportation Systems program has given new impetus to implementation of variable speed limit systems. FHWA supports additional development of variable speed limits in work zones, and has awarded funding for field tests in Michigan, Maryland, and Virginia. These field tests do not use a fixed posted speed, but measure real-time traffic, then compute and post a speed limit reflecting the safe speed at which drivers should be travelling. As a general rule, if a variable speed limit sign lowers the speed limit because workers or other hazardous conditions are present, the hazards should be evident to drivers. Enforcement agencies need to be informed of changes in the speed limit in order to effectively provide speed limit enforcement and to document the speed limit that is in place when the fine is issued.

Kwon (Kwon et al, 2006) implemented a system at one of the I-494 work zones in Minnesota, for a three week period in 2006. The proposed system adopted an efficient, two-stage speed reduction approach using real time measurements downstream and upstream the work zone for determining Variable Speed Limits (Figure 4-2). By providing advisory speed levels to drivers approaching a congested work zone segment, the system tries to minimize the potential for rear-end collision and mitigate the negative impacts of shock waves.

The field data collected in the before and after periods clearly indicates the effectiveness of the system in reducing the longitudinal speed differences along the work zone area during the 6:00-8:00 a.m. peak periods on weekdays, i.e., 25-35 % reduction in terms of the average 1-minute maximum speed difference. This resulted in approximately 7% increase of the mean speed measured at the downstream work zone boundary during the 6:00-7:00 a.m. periods, while the increase on the 7:00-8:00 a.m. periods was not significant.

Results of a field test with a variable speed limit (VSL) system in a work zone in Michigan 2002 (Lyles et al, 2004) showed positive effects on average speeds and travel time through the VSL deployment area. A review of the crashes showed that most were rear-end collisions, most occurred in the non-VSL direction, and none appeared to be directly associated with the deployment of the system, so the VSL system did not create safety problems.

Based on a test conducted to investigate the use of VSL signs in the State of Utah (Riffkin et al , 2008) the response and long term application of VSL signs is very positive. VSL led to lower average speeds than static speed limits signs through the construction zone, also the variance in speed distribution was reduced. During evening conditions with the VSL sign set to 104 km/h (65
mph), the standard deviation of speeds reduced by between 2.4 to 8 km/h (1.5-5 mph). The use of VSL signs can cause safer work zones and more effective speed regulations. Following the results of this research it was recommended that VSL signs should be placed with the same spacing as the static signs, which may result in the need for additional VSL signs and higher construction costs.

A report prepared in the UK (Mott MacDonald, 2007) contained an interesting review about Variable Speed Limits Usage in Europe.

- VSL have been used on the UK M25 to reduce stop and go driving and to smooth the traffic flow. Police officers and drivers reported to have been impressed with the system, with 68% of drivers agreeing that the system should be extended. The use of VSL on the M25 also showed a 10-15% drop in accident rates. However, this study showed that the use of signs on their own was not effective and drivers only complied with the speed limit when they observed a ‘flash’ of the camera.

- A trial in Finland, implemented to face adverse weather conditions, showed that 95% of the drivers interviewed were satisfied by use of the system. Variable speed limits were found to be particularly useful in reducing drivers’ speed during ‘slippery road conditions’, especially since such conditions are not always easy to detect.

- In the Netherlands, VSL have been used to reduce speed during foggy conditions; and to combat “shockwaves” (periodic, sudden, traffic speed reductions) and congestion. Results have shown that installation of VSL prompted drivers to reduce their speed by 8-10 km/h during fog. When used for congestion, the majority of drivers were in favour and obeyed the VSL. This system has led to a 23% decline in the accident rate.

- German motorists were also found to respond well to the speed limitation when the variable speed limits changed between 100km/h, 80km/h and 60 km/h. Variable speed limits with lane controls on the German Autobahn reduced injury accidents 20-29%.

Fudala & Fontaine (2010a) used a calibrated simulation model to evaluate the influence of several parameters in VSL implementation. The simulation also showed that VSL sign location is extremely important, and signs must be positioned so that the drivers will accelerate back to a reasonable speed once they pass through a bottleneck. On the other hand VSLs can delay the onset of congestion and help produce more rapid recovery from congestion, provided that demand volumes are not too far above the work zone capacity. When demand volumes are extremely high, VSLs offer no appreciable benefit over static speed limits. Furthermore, a cost/benefit analysis indicated that VSLs may be mostly appropriate for long-term applications (Fudala & Fontaine, 2010b).

An Austroads research project developed recommendations for consistent application of variable speed limits in Australia (Austroads, 2009). The research revealed that VSL have in general significant safety benefits. According to the results of this study speed limit should be selected based on the threshold of traffic volume, congestion, speed, peak period crashes, and inclement weather crashes. The application of VSL in some cases did not substantially contribute to improving traffic flow.

A Swedish project (Trafikverket, 2011) compared a number of methods to reduce the travel speed of vehicles passing through a stationary work zone. Three different techniques have been used to evaluate and compare the reduction of the speed of vehicles passing a stationary work zone with maximum speed 30 km/h:

1) passive, mobile speed barriers,
2) digital road sign presenting the speed of the passing vehicle,
3) “active speed barrier” (bump size depending on the speed of the passing vehicle).

Work zone without these methods of speed reduction was used as reference. All methods reduced the mean speed compared to reference and furthermore the variation of speed between different vehicles was reduced (fewer vehicles with extremely high speed).
4.2.2 Speed monitoring displays

Speed monitoring displays (SMD), also known as mobile radar trailers, were developed in the late 1980s (Figure 4-3).

SMDs are usually stand-alone systems that can be placed individually, or in a series. The system consists of a self-contained trailer unit equipped with radar to measure the speed of approaching vehicles. The display boards are generally not used to enforce the speed limits. Approaching vehicle speeds are displayed on LED panels along with the posted work zone speed limit, and a message stating “Your Speed”. The systems are typically battery powered to last at least one week. These speed reductions are assumed to occur in two ways: drivers read the display, realize that they are speeding and choose to slow down otherwise motorists with radar detectors will be likely to slow down when their detectors are activated by the radar signals.

Speed display units may be used in any type of work zone, but because of the cost and installation requirements they are mostly appropriate on roadways with higher volumes or speeds. Several studies have been conducted to evaluate the effectiveness of SMDs in work zones. This section gives a brief review of the available research related to this speed management technique.

A research project conducted by the Texas Transportation Institute identified the effectiveness of different work zone traffic control technologies (Carlson et al, 2000). A SMD was tested on two rural high-speed temporary work zones. The “before” data were collected in the morning and “after” data in the same days afternoon. A speed reduction of 3.2 to 12 km/h (2-7.5 mph) upstream of the work zone and 4.8 to 9.6 km/h (3-6 mph) within the work zone resulted from the evaluation.

A study conducted by Clemson University (Sarasua, 2006) evaluated the effectiveness of an SMD display incorporating a Variable Message Sign with a text. Researchers decided to use the following message sequences:

- STAY ALERT – WORK ZONE
- WATCH SPEED
- YOU ARE SPEEDING

The first message sequence was programmed as the base message continuously displayed, while the latter two were triggered whenever a vehicle exceeded a preset threshold. Mean speed was reduced by 4.6 to 7.4 km/h (2.9 to 4.6) and the 85th percentile was reduced by 3.2 to 6.4 km/h (2-4 mph).

A Swedish study showed that speed displays on slow moving work vehicles had a major impact on speed, with a mean speed reduction of 24 km/h and an 85 percentile reduced by 47 km/h. The signs are particularly useful on motorways and larger rural roads (Kalman, & Sjöholm, 2010). In
Finland, however, it was found that showing the road user’s speed on variable message signs placed on the working vehicle may draw the road user’s attention to the sign instead of to the worker and to the work zone and recommended mounting a flashing camera on the sign (Kalman, & Sjöholm, 2010).

Recent studies have proven the long-term effectiveness of radar speed monitoring displays. Portable trailer mounted displays are appropriate for temporary speed reduction needs such as work zones. Long-term speed management needs however are better served with a permanently mounted speed monitoring display (Saito & Bowie, 2003).

Pesti and McCoy (1995) evaluated the long-term effects of speed monitoring displays. Three display trailers were deployed for five weeks in two work zones on an interstate highway in Nebraska. The mean, the 85th percentile and the standard deviation of approach speeds and the percentage of vehicles complying with the speed limit were evaluated. Researchers determined that display trailers were effective in lowering speeds, increasing uniformity of speeds, and increasing speed limit compliance. The effectiveness lasted also after the removal of the SMD, although they were less pronounced than during the deployment.

Brewer et al (2005) tested speed display trailer and compared the effectiveness with Variable Message sign and the orange – border speed limit sign used in Texas. Results indicate that devices with the ability to display drivers’ speeds have a noticeable effect on improving compliance. The mean speeds measured at the two nearest measurement locations downstream of the device resulted in a mean reduction of 5 km/h (2.1 km/h) for both passenger cars and trucks. The other devices improve the visibility and conspicuity of speed limit signs, but they did not have a consistent measurable effect on compliance.

The Center for Transportation Research and Education (CTRE) conducted a survey to learn more about other state policies regarding work zone speed reduction and management (Maze et al, 2000). Six agencies indicated that they used speed displays in their work zones. With perceived speed reductions estimated at 4.8–8 km/h (3-5 mph), the Arizona DOT described the system as partially effective. The Ohio Turnpike Authority reported that the system is ineffective. Moreover, the New York State Thruway Authority indicated that the system was initially effective but became less effective after an extended period of time. The Minnesota DOT reported a 6.4–9.6 km/h (4-6 mph) speed reduction using the display. The Wisconsin DOT indicated having limited use of the displays so far, with mixed comments on their effectiveness in reducing speeds at work zones.

4.2.3 Variable message signs
A commonly used device to increase driver awareness in work zones is a text Variable Message Signs (CMS in Figure 4-4 ). CMSs can provide drivers with real-time information about conditions, and can be particularly useful at work zones where unexpected traffic or detour situations exist. Often a variable message sign is equipped with radar and has the capability to determine the speeds of approaching vehicles. They have been in use for decades and are divided in portable and permanent. Permanent variable message signs are often fixed along or above roadways and relay information pertaining to roadway conditions, travel times, and special events. Portable variable message signs (PVMS) are most often found in work zones, providing special instructions, warnings, or other information to motorists.
The decision to use VMSs is based on a number of factors including availability, reliability of equipment, and installation and maintenance costs. VMS effectiveness on reducing speeds is strictly connected to placing a message on the sign only when there is a specific activity or condition that really requires the message. The signs should be capable of being operated remotely with a list of messages developed prior to the beginning of the construction activity. The number of signs and the distance of the first sign from the construction site would be dependent on the characteristics (speed, traffic volume, roadway geometries) of the specific work zone.

The survey conducted by CTRE (Maze et al, 2000) reported that more than half (18 agencies) use VMS in their work zones. Four agencies perceived the strategy to be effective. The North Carolina DOT recorded a 4.8-8 km/h (3-5 mph) decrease in the 85th percentile speed. Similar to the regulatory speed sign usage, the Arizona DOT reported estimated 30–50 percent speed limit compliance when implementing the VMS system in its work zones. The Kansas Turnpike Authority and Wisconsin DOT indicated that the system is somewhat effective.

Brewer et al (2005) have shown that the PCMS reduced mean speeds for both passenger cars and trucks at the two nearest measurement locations downstream. The most significant reduction in mean speed, evaluated in many locations in Texas work zones, was 3.4 km/h (2.1 mph) for passenger cars and 2.1 km/h (1.3 mph) for trucks. The most significant reductions in the 85th percentile of speed were 3.2 km/h (2 mph) for passenger cars and 1.6 km/h (1 mph) for trucks.

In 1995, a research team examined the effects of the following four messages in Virginia work zones (Garber & Patel, 2001)

- YOU ARE SPEEDING, SLOW DOWN
- HIGH SPEED, SLOW DOWN
- REDUCE SPEED IN WORK ZONES
- EXCESSIVE SPEED SLOW DOWN

When comparing driver responses to each of these four messages, there was not a significant statistical difference in the ability of the messages to reduce vehicle speeds. The four messages examined produced speed reductions of 8 to 16 km/h (5-10 mph). The first message was the most successful on reducing the mean and the 85th percentile of speeds. In addition, the speed variance between drivers decreased. This message successfully singled out drivers, and the words “YOU ARE” conveyed the meaning that this message was not a general warning.
A study conducted by the Georgia Transportation Institute (Leonard, 2005) determined that the variable message sign with radar does help reduce the adjacent speed of vehicles at two-lane, two-way rural highway locations. Though the speed reduction is small (ranging from 1.6 to 4.8 km/h typically (1-3 mph), the reduction is maintained over time as well as downstream of the sign placement. Specific speed findings were that drivers of passenger cars for both day and night time driving reduced speeds from 3 to 5 km/h (1.9-3.1 mph) adjacent to the sign and sustained a speed reduction downstream of 3 to 3.7 km/h. For heavy vehicles during the daylight hours, the sign did not significantly influence the drivers speed selections. Heavy vehicles operating at night reduced speeds from 3.5 to 5.6 km/h (2.2-3.5 mph) adjacent to the sign and sustained speed reductions ranging from 1 to 7 km/h downstream.

Clemson Researchers, in their study (Sarasua, 2006), selected four sequences to be shown on the display of the VMS (Figure 4-5).

In general the use of VMS Message sequences has shown to reduce the mean speed and the 85th percentile of speed. The mean speed decreased from original values as high as 9.6 km/h (6 mph) above the speed limit to speeds typically within 3.2 km/h (2 mph) of the speed limit. The per cent of drivers speeding was reduced for all messages, varying among the messages: the message “YOU ARE SPEEDING” followed by “SLOW DOWN” was proven to be the most effective in reducing speeds in work zone areas.

A number of evaluations conducted in Sweden on the use of variable signs showed good results (Bolling & Sörensen, 2008). A variable merge point was achieved by using variable message signs in combination with detected speed and queue length. This method resulted in reduced delay and less aggressive behaviour. Variable signs displaying the driver’s speed, detected with the use of radar, showed reduced speed, also after several weeks of use.
4.2.4 Flaggers
In some countries, flagging is a commonly used technique in single carriageway work zones (Figure 4-6). Flaggers are typically used to control the flow of traffic through the work zone. A flagger needs to be placed far enough in advance of the work zone to allow motorists to slow down or stop as required.

The survey conducted by CTRE (Maze et al, 2000) reported that only two agencies use flaggers in their work zones: the Kansas and Wisconsin DOTs both indicated that flaggers with proper placement are very effective in reducing speeds at work zones.

Benekohal and Kastel (1991) conducted a study at a rural Illinois work zone to determine the impact of flaggers on traffic speed. Speeds were recorded as vehicles moved through the work zone. Speed data were collected prior to and after the flaggers were given training to reinforce their knowledge of flagging techniques for rural interstate work zones. This study determined that there was a speed reduction for both trucks and cars as they approached a flagger. This study indicated that the average speeds of cars and trucks were reduced by 18.7 and 14.6 km/h (5.2-9.1 mph), respectively, with flaggers without a specific training. The speed reductions for cars and trucks increased to 23.8 and 19.0 km/h (14.9-11.9 mph), respectively, after the training sessions.

While flaggers can be very effective at reducing traffic speeds, there are several drawbacks associated with their use. Flagging by its very nature is labour intensive, making it costly for long-term use. Moreover, flagging is a physically tiring and boring work. To maintain maximum flagger effectiveness, personnel should be properly trained and rotated on a regular basis.

While various measures have been implemented in recent years to improve the safety and effectiveness of flaggers, crashes involving flaggers still occur and quite often result in serious injury to the flagger. In 2004, the Federal Highway Administration (FHWA) approved the use of Automated Flagger Assistance Devices (AFADs), which are designed to be remotely operated by a flagger positioned outside of the travel lane, thereby reducing their exposure to vehicular traffic. There are two types of AFADs: one type uses a remotely controlled stop/slow sign to alternately control the right-of-way; the other type uses remotely controlled red and yellow lenses and a gate arm to alternately control the right-of-way (Figure 4-7).
Even though researchers think that AFADs may increase the safety of flaggers, there were concerns that motorists may misunderstand AFADs; thus, increasing the potential for motorists to enter the lane closure under the stop condition (Finley et al. 2012).

A flag guard and a pilot to conduct the traffic passing a repair work at a road with a central safety barrier showed to be a good alternative for the purpose of obtaining a regular flow of vehicles passing a repair work at a road with a central safety barrier (Trafikverket, 2011). The outcome is dependent on local conditions such as number of passing vehicles. An opinion poll showed that the road users generally consider the pilot method to be good (26 %) or very good (58%). A great share (68 %) preferred this method as an appropriate solution, to be compared with up to 21 % for other suggested methods. For repair work at roads with a central safety barrier, the method is able to control traffic flows up to the order of 500 vehicles per hour.

The results of computer simulation of the pilot to direct traffic past the repair work on the meeting separated road gives an indication of the flows that can be handled by marshalling the traffic. Flows around 700 vehicles per hour can be guided past a 200-meter road works without average waiting time exceeds one minute. When the flow approaching 800 vehicles per hour occur however problem, but exactly when the limit is reached is difficult to say.

Route 509 outside Öjebyn, Sweden used both piloting and guard on a few occasions (Rosander et al, 2011). Both served very well with all respect to road access and the method's flexibility, but it requires a vehicle, communications, and especially staff. Economically, these costs should be weighed against the possible rental costs of traffic signals and additional signage. The pilot decides what speeds other vehicles should have and can choose to slow down that much where the needs are greatest. In addition, the pilot have a better understanding of the site's unique conditions including were the road workers are than the road users.

4.2.5 Other solutions

In Finland, Denmark and Sweden “particular messages” were tested such as ‘Take care of my father’ and ‘Here my father is making way for you’ or ‘My father works here’ and ‘Take care of me I work for you’. These kinds of messages seem to have very beneficial effects on reducing speeds (Figure 4-8).
The results of velocity measurements show that video surveillance has the potential reducing speed past the work zones (Bolling & Nilsson, 2001). Measured rate effects were in the order of 5 km/h when the speed was measured before and after installation of monitoring equipment and associated signage. It is worth noting that the speed of the effect was independent of the rate level, i.e. deceleration was 5 km/h over the speed range. The decrease in speed when the camera used meant that the number of speeding violations approximately was halved. From the questionnaire responses from the speeders one can see that they were positive about the camera supervised work zone sites.

### 4.3 Physical devices

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

#### 4.3.1 Portable Rumble Strips

Temporary rumble strips are self-adhesive strips that create an audible, visual, and physical alert when driven over (Figure 4-9). These brightly coloured strips are intended to warn drivers of an approaching work zone where they may be required to stop, merge, or simply slow down.

Heaslip et al. (2010) conducted tests on portable rumble strips placed on a closed roadway surrounding Kansas City and in a closed park-and-ride facility in Kansas. The rumble strips tested in this study were two different types of reusable temporary rumble strips made out of steel with a
rubber bottom and four generations of plastic rumble strips. After comparing lateral movement results, it was concluded that the first-generation plastic rumble strips moved such a large amount when traversed by a heavy truck that they would not be ideal for use at a work zone of any kind, especially one with higher speeds where heavy trucks could pass.

Wang et al (2011) tested Portable Plastic Rumble Strips (PPRS) on two-lane two-way rural highways where maintenance activities were completed within a single day. The results of this research revealed that the addition of PPRSs, as a supplement to standard flagger control, did create a 7.4 to 18.8 km/h speed reduction for cars at short-term work zones with lane closure on two-lane highways. The effects of the PPRSs on truck speed reduction were not significant at one of the test sites, but they still created 8.1 to 18.8 km/h mean speed reduction for trucks at the other two sites. Although the speed reduction for trucks was not significant at one of test sites, the highest percentage (78 percent) of truck drivers hitting their brakes at the PPRS locations was found at that site. It was indicates that the PPRSs still gained the attention of truck drivers even though the effects were not shown in the speed reduction.

The Indiana DOT tested rumble strips at several locations and found that the strip cracked easily and moved when trucks passed over it. It also noted that some drivers swerved around the strip to avoid it since it looked like a flat tire in the roadway. The Maryland, Utah, and Arkansas DOTs also noted this phenomenon. New Mexico DOT found that the strip wore out quickly, which created a hazard since this exposed the devices used to hold the rumble strip in place. None of the DOTs that studied the portable rumble strip recommended its use (Trout & Ullman, 1996).

In Sweden an inflatable system known as the “green bump” (Figure 4-10) has recently been tested. The speed is detected by radar in advance to the system and a warning is given to the driver on a variable message sign. If the speed is not reduced enough the bump will be inflated (Kalman & Sjöholm, 2010). The effectiveness of this system on reducing speed has to be evaluated.

Another easily and quickly movable (10–15 minutes) system known as ‘Active Safety Roads’ has also been developed (Figure 4-11). The modular facility enables adjustment of length and width of this bump. The system can be combined with another system including radar and a radar triggered VMS on a sign trailer.
The main factors resulting in low vehicle speeds were:
- when the speed limit was posted by speed limit sign, compared with a recommended maximum speed sign,
- when the lane was narrow,
- then the speed bump in the form of mini bumps used,
- or surface been bumpy and of poor quality.

The results of road 97 between Boden and Luleå, Sweden also showed that the speeds were lower near the asphalt machines compared to further away (Rosander et al, 2011). An example from the same road showed that the percentage of vehicles that violated the speed limit on a road work decreased from 77.1% down to 1.3% when using reduction of the lane width and speed bumps.

4.3.2 Narrowed lane widths
The EU project FORMAT (2004) recommends narrow lanes. Existing lane markings must be removed if there is any danger of confusion between them and narrow lane markings. Vehicle speeds can also be reduced by narrowing the lane widths through a work zone (Figure 4-12).

In general, narrower lanes leave less lateral distance between vehicles in adjacent lanes or between vehicles and shoulder obstructions, increasing motorists’ attention and inducing motorists to reduce speeds. This can be accomplished using a variety of channelizing devices, including delineators (Figure 4-13), traffic cones, drums, and temporary barriers (Figure 4-14).
In major work zones concrete barriers can also be used. By narrowing the lane width, it is possible to create moderate speed reductions throughout the entire length of the narrowed section. Lane narrowing also presents a relatively inexpensive form of speed control for long-term projects since there is usually very little management cost to maintain the narrowing. Although inexpensive and relatively easy to implement, narrowing lane widths can reduce roadway capacity. There is also a greater possibility of vehicles striking the cones or other devices, which could increase the number of crashes in these work zones (Trafikverket, 2011).

In North American experience, lanes that are too narrow (less than 3.0 m) may lead to driver discomfort, difficulty in remaining within the lane, and increased collisions, especially for trucks (Harmelink et al, 2005).

Richards et al (1985) studied the effectiveness of lane reduction for 3.81 m and 3.51 m using cones in six work zones on Texas freeways. The study concluded that this measure achieves a 16 percent speed reduction. The study also noted that devices such as barrels or concrete barriers would be much more efficient and is likely to lower speeds even more.

A study conducted by Missouri University of Science and Technology in 2011 (Bham & Mohammadi, 2011) recommends the use of tubular markers rather than pavement markings for reducing the lane width, and separating the construction area from the open lanes. In fact when the
lane width was reduced using tubular markers, the speed of cars and trucks was reduced by 21.8 and 28.5 km/h for cars and trucks during construction activity, respectively.

Perco and Dean (2011), in a recent study, collected speed data along the approach tangent sections of 11 work zones on two-lane rural roads in Italy. The results show that drivers do not obey the temporary speed limit and that they reduce speeds only when the lane width is reduced, resulting in high deceleration rates. Furthermore the analysis of the speed distributions reveals, in contrast to previous studies conducted in the United States, that speed variances are lower upstream as compared to the approach tangent both for work zones with and without a physical reduction of the carriageway width.

4.3.3 Optical speed bars
Optical speed bars are innovative pavement markings for reducing speeds and decrease the number of accidents in work zones. They are much more common in Europe than Canada or U.S. Optical speed bars are a non-obstructive manner of reducing driving speeds by manipulating the visual environment to induce a perception of higher driving speeds (transverse and peripheral stimuli influence speed perception and driver behaviour). Gradually decreasing the distance between the strips (Figure 4-15) creates the illusion of speeding and causes drivers to decrease their speed.

![Figure 4-15. Example of optical bars](image)

Optical speed bars have been documented to work well with large desired speed reductions. They have also proven to be effective on approaches to roundabouts in Britain (Maze et al, 2000) or at freeway exit ramps where the ramps end at a STOP sign or traffic signal. However there are fewer studies concerning the effectiveness in work zones.

Hildebrand et al (2003) evaluated transverse speed bars on one rural highway work zone in a five-week experiment and compared the effectiveness between night and day. The results showed that the night-time conditions had a greater reduction in speed in comparison to daylight hours. The transverse speed bars appeared reducing the mean speed and the increased contrast of reflective marking tape during night-time conditions contributed to improve results.

VTI tested optical speed bars in one direction on a two lane rural road in Sweden (Sörensen & Wiklund, 2011). The section was 200 meters long and ran from a 70 km/h speed limit sign to a 50 km/h speed limit sign. The 30 cm wide bars were fixed onto the road surface, at an angle of 90 degrees to the direction of travel, along both edges of the traffic lane. Speed measurements at the beginning and end of the section, before and after the introduction of the optical speed bars has shown a small reduction in mean speed at the end of the section.
Many studies have been conducted with driving simulators to evaluate the effectiveness of this treatment in terms of speed reduction even though they do not specifically refer to work zones.

Godley et al (2009) conducted several experiments with a driving simulator (Figure 4-16). Treatments included, among the others, transverse lines and peripheral transverse lines. Several of the countermeasures evaluated were effective for reducing speeds. All configurations lead to a speed reduction: in terms of cost / benefit ratio the peripheral bars resulted the best treatment.

In a study conducted by the University of Naples (Italy) (Mauriello, 2010), 10 different alternative configurations of elements were tested (Figure 4-17).

The presence of perceptual countermeasures was effective for changing driving behaviour of users, improving the perception of intersections and driving style. Each configuration reduced
mean speeds compared to the intersections without any treatment with speed reductions ranging from 11 km/h to 23 km/h. Comparing the lateral positions between the alternatives with and without treatment significant differences were identified. The use of perceptual countermeasures increased the number of drivers who slowed down and changed their deceleration rate. The maximum reduction of speed (23 km/h) was observed for the treatment rumble strips plus coloured intersection at a distance of 75 m from the intersection.

4.3.4 Other solutions

Other speed management solutions for work zones can be:
- Chicanes
- Separation of opposing traffic flows;

A chicane (Figure 4-18) is a traffic management solution characterised by a change in the alignment of the traffic flow on the carriageway. A motorist passing through a chicane is forced to change directions twice in quick succession, typically reducing the speed to do so.

![Figure 4-18. Example of chicane Nygårdhs (2007)](image)

A study conducted by Nygårdhs (2007) compared three different types of arrangements for chicanes (Figure 4-19). A comparison with conventional equipment used in Sweden was also conducted.
The arrangement using a white barrier was considered more clear than the others. However, even though in general the presence of the chicane lead to a lower mean speed, the high clarity also seemed to lead to higher speeds.

The approaches used to separating the opposing traffic flows can also affect the travel speeds. In the EU project FORMAT (FORMAT, 2004) the VTI trial used four different methods:

- No marking
- Vertical delineators
- Orange lines
- Studs

The results suggested that the vertical delineators were the most effective in achieving good separation between traffic in different lanes (directions) and in reducing speeds. However, drivers actually preferred the use of either lines or studs.

The TRL trial (FORMAT, 2004) implemented three different layouts using lines to separate the lanes (with traffic travelling in the same direction in both lanes):

- White lines as normally used at narrow lane sites in the UK
- Shorter white lines – intended to give an impression of increased speed
- Yellow lines spaced as for the standard markings but with the original white lines left in place

There was little difference in speed through the works with the three lane markings, although there was a suggestion that speeds were lower when yellow lines were used (Figure 4-20).
4.4 Enforcement measures

Enforcement measures are used to enforce speed limits by automated speed monitoring, speeding detection, imposition of violation fines, and presence of police cars. In general police enforcement is perceived to be one of the most successful work zone speed reduction strategies. The survey conducted by CTRE (Maze et al, 2000) reported that out of the 26 agencies that included police enforcement in their work zone speed control plans, 18 agencies (69 percent) indicated that the strategy is very effective in managing speed at work zones. Half (4) of the remaining agencies indicated that using police enforcement was partially effective.

A Canadian (Harmelink, 2005) survey regarding the effectiveness of police enforcement, indicated that 55% of respondents rated their effectiveness as high, 30% as moderate, 10% as low, and 5% as not effective. In general, most speed reduction measures are likely to be more effective if they are supported by police enforcement. There are also some speed reduction measures that are unlikely to be effective unless supported by some level of police enforcement. Measures that have proven to be effective in helping to manage speeds in work zones include police presence and enforcement in the work zone, automated speed enforcement and, with less success in terms of reduction of speed, radar drones.

4.4.1 Police in work zone

An observable police enforcement strategy can involve mobile or stationary police cars. In general a police officer stationed at one point significantly increases the speed limit compliance at that location. On the other hand, a circulating police car covers a larger area but is less effective at speed reduction. Richards et al (1985), examined the effectiveness of focused law enforcement using stationary and mobile applications in six work zones on rural and urban highways in Texas. The study indicated that a stationary patrol car reduced mean speeds by 8-18.9 km/h (5.6-11.8 mph). A circulating patrol car was found to reduce speeds by only 3.2-4.8 km/h (2-3 mph), indicating a lessened effectiveness compared to a stationary approach.
The Minnesota DOT examined the effectiveness of police enforcement in work zones at three different sites during 1999 (Minn DOT, 1999). The sites were a rural interstate, an urban freeway, and a metro location. Speed data were collected using a laser gun and without an enforcement vehicle present. The patrol car was located upstream of the work zones, with lights and flashers activated. The posted speed limit on the four-lane divided interstate was 112 km/h (70 mph) which was reduced to 74 km/h (45 mph) in the work zone area during construction. The study found that the 85th percentile speed was reduced from 81.6 to 68.8 km/h (51 to 43 mph) when a police vehicle was parked upstream of the work zone. Similarly, for the urban freeway with a posted speed limit of 88 km/h (55 mph) and for the metro location with a posted speed limit of 80 km/h (50 mph), the 85th percentile of speeds were reduced from 105 to 92.8 km/h (65.5 to 58 mph) and from 92.8 to 75.2 km/h (58 to 47 mph), respectively. The presence of law enforcement improved compliance with posted speed limits.

The long-term effects of police presence were evaluated in Michigan on Interstate 96 during 1996 (Sisiopiku and Patel, 1996). This study indicated an average speed reduction of 8.8 km/h (5.5 mph) for vehicles approaching a parked police car. Upon passing the police car, however, drivers tended to return to original speeds or higher. The study reported no discernible changes in speeds one, two, and three hours following police presence.

A study by Hajbabaie et al. (2009) compared the effects of four speed management techniques on speed on interstate highway work zones. The techniques are a speed feedback trailer, a police car, a speed feedback trailer plus a police car and automated speed photo-radar enforcement (SPE). The effects on the mean speed and on the degree of speeding were studied. The results showed that all law enforcement treatments (including variations of police presence and SPE) significantly reduced the mean speeds and degree of speeding: the trailer plus police presence reduced the mean speeds more than the other treatments.

The previous results demonstrate that a combination of more than one device could improve speed compliance through the work zone. The location of police vehicles in relation to the work zone also needs to be considered. This could be in advance of the work zone (upstream); within the work zone; and beyond the work zone (downstream). Generally, it is beneficial to position police vehicles upstream or at the beginning of the work zone, because of its powerful effect in getting vehicle speeds down before they enter the work zone. Several Canadian provincial road authorities have indicated that they consider this to be the most effective location (FORMAT, 2004).

In the US, the Federal Highway Administration proved that staffed police cars with flashing lights at the beginning of the work zone are an effective way to reduce the average speed (Hajbabaie et al., 2009). Other results were:

- Officers being positioned inside the work area increase worker safety because of slower speeds in the vicinity of the work zone
- A minimum of two officers should be used in work zones, one stationary and continuously on site and one for enforcement
- The use of an unmarked vehicle is a common state police tactic to apprehend violators

However, if a speeding vehicle is to be pursued the pursuit will take place, at least in part, within the work zone, which is undesirable.

A dummy police vehicle can still be considered as a type of stationary enforcement (Figure 4-21).
Another possible strategy to reduce speeds consists in parking empty patrol vehicles (or with a mannequin inside) at or near work zones, in an effort to persuade drivers that enforcement is active and motivate them to slow down towards the posted speed. Care must be taken that vehicles are not parked in a position to create a collision hazard or a sight distance obstruction.

The cost and effort of this treatment is very minimal, and it can be very effective for short periods of time, especially for non-regular drivers. Dummy vehicles can sometimes be used effectively, saving police resources, but drivers soon realize that there is no real enforcement, unless real police vehicles are also used from time to time in the same location, keeping drivers in the doubt (FORMAT, 2004).

The survey conducted by CTRE (Maze et al, 2000) reported that out of the 34 agencies that responded, only two reported using this strategy. The North Carolina DOT, that puts a mannequin inside the police car, reported reducing the 85th percentile of speeds by 4.8–8.0 km/h (3–5 mph) in the first few weeks of deployment. However the New York State Thruway Authority described the strategy as moderately effective.

Two modes of police enforcement were also applied on Delaware’s interstates:
  • empty police car equipped with radar and flashing lights;
  • an officer standing at the entrance of the work zone, motioning vehicles to reduce their speeds.

The study indicated that both of these measures reduced speeds in single- and multi-lane closures on interstate work zones.

4.4.2 Automated speed enforcements

Automated speed enforcement devices utilize a radar or laser devices to detect speeds of oncoming traffic. The device takes a picture of the vehicle’s license plate (and of the driver if needed in certain jurisdictions). With this solution officers do not have to pursue, or attempt to pull over, vehicles within the work zone (Figure 4-22).

Spot enforcement can be labour intensive and costly with long term use. However semi-mobile speed cameras (installed for several days) are more and more used, typically in Belgium for safety sensitive road work sites. Unfortunately the literature search didn’t reveal any published references reporting about the time and special effectiveness of the measure.
Researchers proposed a similar idea for remote enforcement to use an officer with a remote device to enforce the work zone speed limits. The device is upstream of the work zone, while the officer is positioned downstream to issue citations to violators. When an upstream violation occurs, the device records the picture and sends the image to the officer, who issues the citation; this keeps the actual enforcement activity out of the work zone, where the space for police vehicle to park and the space to pull vehicles over is greater (Wang et al, 2011, Brewer et al, 2005).

A study conducted in Illinois (Wang et al, 2011), investigated the headway distribution of vehicles in work zones with and without automated Speed Photo Enforcement (SPE). The results indicated that the mean headway of cars increased when the SPE van was present compared to the base condition. It was also found that the proportion of cars travelling with a very short headway in the median lane significantly decreased when a SPE van was present at one work zone.

In 2007 the Oregon Department of Transportation made an evaluation of an initial photo radar installation in a highway work zone (Joerger, 2007). Photo radar enforcement had a substantial impact on reducing the number of speeding vehicles in a construction work zone. Speeding was reduced by an average of about 24%.

Benekohal & al (2009) tested the effectiveness of SPE systems on the basis of three data sets collected in two work zones with speed limit of 88 km/h (55 mph). SPE was effective in reducing the average speed and increasing compliance with the work zone speed limit in all three data sets. In almost all cases in which SPE was implemented, the average speeds were significantly lower than the work zone speed limit.

In Maryland three different sites were selected to measure the spatial and temporal effect of automated speed enforcement on motorists’ speeding behaviour (Franz & Chang, 2011). For data sets that compared the before versus during analysis periods, the enforcement period displayed a general reduction in aggressive motorists (travelling more than 16 km/h (10 mph) over the posted speed limit). At the same time, a more stable spatial speeding distribution through the work zone was induced. Two of the three data sets comparing the “during enforcement” period versus the “after enforcement” period showed that motorists may learn where enforcement is taking place and adjust their speeds accordingly.

Another, relatively new speed enforcement technique, is the average speed control (also called ‘section control’ or ‘point-to-point’ control) that records the average speed over a road section. The vehicle is identified when entering the enforcement section, and again when leaving it. The average speed can be calculated based on the time interval between these two points. These systems resulted to be very effective in ordinary motorway sections but usually are not applied in work zones as they require long uniform travel sections (typically of approximately 10 km).

4.4.2.1 Radar drone
Radar drones are electronic radar systems that transmits in the microwave-frequency band and has the ability to emulate radar frequency up to one mile (Figure 4-23). When detected by in-vehicle radar detectors, drivers are tricked into thinking police enforcement is ahead. Drone radars can be used to deceive drivers of police presence in work zones and in ghost police cars.
A very complete review on these types of devices was conducted by Clemson University (Sarasua et al, 2006). Many studies examined the speeds before the drone radar detection, where the drone radar is detected and after the detection to determine if the device has a lasting effect on speeds. However, a very important problem for these studies is related to the difficulty of determining the presence or absence of radar detectors inside vehicles. The effectiveness of this speed management solution, in fact, is directly related to radar detector usage. For example, many trucks have radar detectors, making a truck act as an “enforcement” which will lower overall speed. Higher success at night could be because of the higher percentages of truck traffic as well as the perceived difficulty in identifying the location of law enforcement. In the past, radar detector usage was determined through visual inspection which is a very complex technique to be applied. Without a device to sense the radar detector, it is impossible to determine exactly the percentage of vehicles for a highway equipped with these devices. In recent years, the development of the radar detector detectors has made it possible to detect vehicles possessing radar detectors illegally.

For several studies (Sarasua et al, 2006, Bolling and Sörenson, 2008), the use of radar drones initially shows positive effects. Vehicles equipped with radar warning systems reduce their speed. This method mainly has an effect on the highest speeds but the drivers soon find out that there is no real enforcement and the positive effect tends to disappear.

Benekohal et al (1992) studied the effectiveness of drone radar at a rural work zone in Illinois. They conducted three different experiments to evaluate also the long term effectiveness of the drone radar. The first experiment, to evaluate the short term effect, lasted about an hour: this experiment was effective in reducing mean speeds by 12.8–16 km/h (8-10 mph). The second experiment, conducted for a few hours using one radar gun, indicated no speed reductions: by monitoring CB radio conversations, researchers discovered that motorists were able to determine that the radar emissions were drones without a real enforcement. The third experiment, using two radar guns in different locations for three hours indicated a major effectiveness of the device: in this case, speeds were reduced by 4.8-9.6 km/h (3-6 mph) for trucks and by 4.8 km/h (3 mph) for cars.

In a study conducted by the Texas Transportation Institute with The Texas A&M University the radar drone was identified by motorists as actually influencing them to slow down. The other devices such as fluorescent orange signs, fluorescent yellow-green vests, vehicle visibility improvements and flagger strobes seem to have a negligible impact on vehicle speeds (Carlson et al, 2000).

Clemson researchers conducted experiments with drone units in a variety of configurations at different work zone sites on Interstate and State Route highways in South Carolina (Sarasua et al, 2006). Results from this study show a 3.2 km/h (3 mph) decrease in mean speeds of all highway vehicles and a 9.6 km/h (6 mph) decrease in those equipped with radar detectors.
A survey conducted by the Center for Transportation Research and Education (Maze et al, 2000), Massachusetts DOT was the only agency, among 25, that recognized the drone radar as its most effective speed reduction strategy (the drone radar is the only device used on all Massachusetts National Highway Roadway systems since July 1996).

The mixed results of drone radar indicate that there is a lot of variability in the experiments conducted. Drone applications could offer good potential for reducing speeds if combined with other strategies.

### 4.5 Conclusions

Several methods have been used for controlling work zone speeds. These methods can be information (signs, flaggers, etc.), physical systems (rumble strips, chicanes, lane width restrictions, etc.), and enforcement (police presence). All of these methods have shortcomings in terms of effects. Some of the most promising are those related to speed monitoring and variable message signs where the driver is provided real time information on their speed. Static traffic signs appear to provide some speed management effects but there were no consistent results from the different documents reviewed. Police enforcement had some of the largest effects but only when the police presence was connected to active enforcement activities.

The main conclusion from the speed management review was that work zone speeds tended to have more uniform speed distributions, but reductions in average speeds only small without a dynamic system (variable messages, police enforcement).
4.6 References


Swedish National Road and Transport Research Institute. Linköping


Riffkin P.E., McMurtry T., Heath S., Saito M., 2008. "Variable speed limit signs effects on speed and speed variation in work zones". InterPlan Co for Utah Department of Transportation Research and Innovation Division


Trafikverket, 2011. The Swedish Transport Administration “Slutrapport Säkrare vägarbetsplatser – Resultat från genomförda försök för att dämpa hastigheter förbi vägarbetsplatser” (eng: Safer road work zones)


5  Review of Graduated Fixed Penalties Programs

Increasing penalties for speeding in work zones could be an effective deterrent to speeding. This practice has increased in last years but is essentially limited to a few countries such as U.S. and Canada. Since March 2011, fines are doubled for speeding offences committed in road work zones in Ontario and Quebec. In Ontario the penalty is double only if workers are present and the amount of fines is from $60CDN (43€) for speeds of 10 km/h over the posted speed limit up to $975 (695€) for speeds 50 km/h over the posted limit (Appendix A).

The Transportation Association of Canada (TAC) made a survey of 55 provincial, territorial, municipality, and road construction managers. Only 16% of the survey respondents rated the effectiveness of this solution as high, the others indicated graduated fixed penalties as moderate or not effective (Harmelink et al, 2005).

In the U.S., fines for speeding and other traffic violations in work zones vary from state to state states (Appendix A). An investigation of the Caltrans Division of Research (Caltrans, 1999) found that:

- 32 states and the District of Columbia double fines in work zones;
- Thirteen states apply fixed fines that range from $50 to $2000 (37-1490€);
- The laws of 24 states and the District of Columbia require the presence of workers for the enhanced penalties to apply;
- 41 states and District of Columbia require the presence of signs in the work zone for fines to apply;
- Laws in six states (Georgia, Nevada, New York, South Carolina, South Dakota and West Virginia) include the possibility of jail time for work zone violations.

New York legislation considers speeding in a work zone a more serious offense than regular speeding (Appendix A). For a speeding in work zone conviction, the basic minimum fines is double and for a second work zone speeding conviction, the maximum fines could be even more expensive. In addition, two convictions for speeding in a work zone within an 18 month period will result in an automatic loss of the driving license (for regular speeding offenses, the licence is automatically revoked after three speeding convictions within the same time period). Finally, while rare, up to 30 days of imprisonment can be ordered for a speeding conviction of 176 km/h (110 mph) in a work zone.

The Texas Transportation Institute evaluated the effect of the “double-fine” law on work zone speed between November 1997 and May 1998 at 10 different work zone construction projects (Ullman et al, 1999). The results didn’t show appreciable effect on speeds at the sites examined: changes included both increases and decreases in average speed between the before and after conditions, while at some sites, average speeds increased in one direction but decreased in the other.

Roberts and Smaglik (2012) studied the influence of double fine signing on driver behaviour. They used variable message signs with radar and analyzed before and after data. They compared two conditions - when speed only was displayed and when both speed and fine messages were on the sign. They concluded that the solution with the “actual speed plus fine” message performs better. The mean speed was 4.8 km/h lower than in the “before” scenario, the 85th percentile of the speeds was reduced by 4.8 km/h and the number of speeders (travelling at more than 24 km/h above the limits) was reduced by half.

It is interesting to highlight that some U.S. states with the most expensive penalties for speeding still observe relatively high motorist fatalities in work zones. In any case, the
effectiveness of this measure clearly depends on effective presence of enforcement. A report by the Texas Transportation Institute at Texas A & M University (Ullman et al, 1997) indicates that states that enacted legislation to increase fines in work zones did not experience significantly lower fatal accident rates than states without fines. Fatal accident experiences in those states after implementation of a graduated fine law were not significantly different than those of the states that did not enact any work zone-related legislation (Table 5-1).

Where the speed limit reductions are perceived to be excessive, fear of a doubled fine was little or no deterrent. Furthermore, statistics shown that nearly 3 out of 10 motorists stopped for speeding in local highway construction zones since January 2011 paid less than the standard fine for their crimes. That is because showing up in court almost always results in a lower fine. A review of more than 4500 tickets issued in work zones around the I-71/670 interchange and on I-270 found that more than 93 percent of people who went to court instead of mailing a check or entering a credit-card number online walked away with reduced or dismissed fines. For example, prosecutors sometimes drop speeding charges in order to win guilty pleas on drunken-driving or other, more-serious crimes. Sometimes, they offer to reduce fines to avoid time-consuming trials. Other times, the police officers who write the tickets don’t show up in court, forcing prosecutors to dismiss tickets. In summary, increased severity or higher fines may have little or no influence on behaviour as long as drivers believe the risk of being stopped and/or cited to be acceptably low. (Ullman, et al 1997).

Table 5-1. Effect of Increased Fine Legislation on Work Zone Fatal Accidents (Ullman et al, 1997)

<table>
<thead>
<tr>
<th>State</th>
<th>Available Yrs After Law Implemented</th>
<th>Change From Expected Fatal Accidents After Law Implementation</th>
<th>Significance of Change (Z-Statistic)</th>
<th>Comparability of Control Group of States</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delaware</td>
<td>4</td>
<td>+40%</td>
<td>0.68</td>
<td>3.45</td>
</tr>
<tr>
<td>Indiana</td>
<td>2</td>
<td>-4%</td>
<td>-0.19</td>
<td>7.03</td>
</tr>
<tr>
<td>Iowa</td>
<td>2</td>
<td>-2%</td>
<td>-0.03</td>
<td>3.80</td>
</tr>
<tr>
<td>Maryland</td>
<td>4</td>
<td>-13%</td>
<td>-0.46</td>
<td>18.22*</td>
</tr>
<tr>
<td>Minnesota</td>
<td>2</td>
<td>-18%</td>
<td>-0.43</td>
<td>1.15</td>
</tr>
<tr>
<td>Missouri</td>
<td>1</td>
<td>+4%</td>
<td>0.12</td>
<td>6.62</td>
</tr>
<tr>
<td>New Hampshire</td>
<td>1</td>
<td>+147%</td>
<td>0.99</td>
<td>0.20</td>
</tr>
<tr>
<td>New Jersey</td>
<td>1</td>
<td>-87%</td>
<td>-3.48b</td>
<td>22.10b</td>
</tr>
<tr>
<td>Ohio</td>
<td>4</td>
<td>+1%</td>
<td>0.05</td>
<td>11.50b</td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>3</td>
<td>+43%</td>
<td>1.54</td>
<td>4.30</td>
</tr>
<tr>
<td>South Carolina</td>
<td>1</td>
<td>-100%</td>
<td>0.23</td>
<td>7.43</td>
</tr>
<tr>
<td>Virginia</td>
<td>3</td>
<td>+299%</td>
<td>4.22b</td>
<td>1.91</td>
</tr>
<tr>
<td>Washington</td>
<td>2</td>
<td>+32%</td>
<td>0.74</td>
<td>6.87</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>1</td>
<td>+10%</td>
<td>0.27</td>
<td>2.28</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>+12%</td>
<td>1.28</td>
<td>33.47c</td>
</tr>
</tbody>
</table>
5.1 Conclusions

Graduated Fixed Penalties is a system where speeding penalties (fines, license demerit points, etc.) are increased for infractions in work zones. This system is exclusive to North America and a summary of fines and effectiveness are presented in Table 5-1. The effectiveness is variable and essentially equivalent to the other speed management methods reviewed in Chapter 4. Active, on-site enforcement appears to be the best method to apply this approach. Drivers are not responsive to static information does not have immediate repercussions or feedback.

5.2 References

6 CONCLUSIONS

A review of work zone speed limits was conducted for several European Countries, Canada, The United States, and Australia. The review is the first technical activity in the ASAP project to establish the state-of-the-art for establishing speed limits, identifying their effectiveness, and evaluated enforcement strategies, especially graduated fixed penalties.

A number of criteria were determined that are used for assigning a work zone speed limit. There were:

• Original posted speed limit
• Type of road
• Impact on traffic flow
• Reduction of lane widths in the work zone
• Presence of workers
• Proximity of workers to the traffic passing
• Changes in road surface properties
• Presence of crossovers and changeovers
• Duration or length of road works

Although some of the criteria listed above are by countries to assign work zone speed limits, there is a great deal of variation in how the factors are used to define speed limits. Many documents refer to subjective interpretation of the conditions and there is no easily identified nomograph, flowchart, or similar procedure that can objectively determine appropriate speed limits. Further analysis with actual speed and safety data is needed to determine if any uniform work zone speed limits can be derived in a generic guideline for Europe.

Of the criteria listed above, the elements most common in the reviewed documents (in descending response frequency) were:

1. Road Type
2. Original Posted Speed
3. Workers Present or Proximity to Workers
4. Duration or Length of road works
5. Lane Width

Several methods have been used for controlling work zone speeds. These methods can be information (signs, flaggers, etc.), physical systems (rumble strips, chicanes, lane width restrictions, etc.), and enforcement (police presence). All of these methods have shortcomings in terms of effects. Some of the most promising are those related to speed monitoring and variable message signs where the driver is provided real time information on their speed. Static traffic signs appear to provide some speed management effects but there were no consistent results from the different documents reviewed. Police enforcement had some of the largest effects but only when the police presence was connected to active enforcement activities.

The main conclusion from the speed management review was that work zone speeds tended to have more uniform speed distributions, but reductions in average speeds only small without a dynamic system (variable messages, police enforcement).

Graduated Fixed Penalties is a system where speeding penalties (fines, license demerit points, etc.) are increased for infractions in work zones. This system is exclusive to North America and a summary of fines and effectiveness are presented in Chapter 5. The
effectiveness is variable and essentially equivalent to the other speed management methods reviewed in Chapter 4. Active, on-site enforcement appears to be the best method to apply this approach. Drivers are not responsive to static information does not have immediate repercussions or feedback.

The reviewed documents had little safety information that can be used to evaluate the different speed limits, speed management, or enforcement approaches in terms of work zone injuries and fatalities. There is information on general work site casualty rates based on annual statistics but detailed analyses were not identified.
7 ACKNOWLEDGEMENT

The research presented in this deliverable was carried out as part of the CEDR Transnational Road Research Programme Call 2012. The funding for the research was provided by the national road administrations of Norway, Sweden, The United Kingdom, Belgium/Flanders, Germany, and Ireland.
Annex A: Speeding Fines for Work Zones

<table>
<thead>
<tr>
<th>State</th>
<th>Violations Affected</th>
<th>Enhanced Penalties</th>
<th>Workers Must Be Present</th>
<th>Signs Must Be Present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alabama</td>
<td>Speeding</td>
<td>Double original fine</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Alaska</td>
<td>All</td>
<td>Double original fine</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Arizona</td>
<td>Speeding</td>
<td>Double original fine</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Arkansas</td>
<td>All moving traffic violations</td>
<td>Double original fine</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>California</td>
<td>Various</td>
<td>Double original fine</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Colorado</td>
<td>All</td>
<td>Double original fine</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Connecticut</td>
<td>All moving traffic violations</td>
<td>Double original fine</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Delaware</td>
<td>Various</td>
<td>At least double original fine (1st offense)</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>D.C.</td>
<td>All moving violations</td>
<td>Double original fine</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Florida</td>
<td>Speeding</td>
<td>Double original fine</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Georgia</td>
<td>Speeding</td>
<td>$100-$2,000 and/or up to 12 months in jail</td>
<td>Either work zone personnel, or barriers, work vehicles or shoulder or pavement drop offs</td>
<td>Yes</td>
</tr>
<tr>
<td>Hawaii</td>
<td>Speeding</td>
<td>$250</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Idaho</td>
<td>Speeding</td>
<td>$50</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Illinois</td>
<td>Speeding</td>
<td>$375 (1st offense); $1,000 (subsequent offenses)</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Indiana</td>
<td>Speeding</td>
<td>$300 (1st offense); $500 (2nd offense); $1,000 (3rd offense within 3 years)</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Iowa</td>
<td>All moving vehicle violations</td>
<td>Double original fine (up to $1,000)</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Kansas</td>
<td>All moving vehicle violations</td>
<td>Double original fine</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Kentucky</td>
<td>Speeding</td>
<td>Double original fine</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

Sources: Governors Highway Safety Association, September 2013
<table>
<thead>
<tr>
<th>State</th>
<th>Violations Affected</th>
<th>Enhanced Penalties</th>
<th>Workers Must Be Present</th>
<th>Signs Must Be Present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Louisiana</td>
<td>Speeding</td>
<td>Double original fine</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Maine</td>
<td>Speeding</td>
<td>Double original fine</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Maryland</td>
<td>Speeding</td>
<td>Up to $1,000</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Massachusetts</td>
<td>Speeding</td>
<td>Double original fine</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Michigan</td>
<td>All moving vehicle violations</td>
<td>Double original fine and at least 3 points</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Minnesota</td>
<td>Speeding</td>
<td>Double original fine (minimum $25)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Mississippi</td>
<td>Speeding</td>
<td>Up to $250 (1st offense), double original fine (subsequent offenses)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Missouri</td>
<td>Speeding or passing</td>
<td>Additional $250 (1st offense); additional $300 (subsequent offenses)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Montana</td>
<td>All</td>
<td>Minimum double original fine</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Nebraska</td>
<td>Speeding</td>
<td>Double original fine</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Nevada</td>
<td>Various</td>
<td>Double original fine (up to $1,000), 6 months jail time, or 120 hrs. community service</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>New Hampshire</td>
<td>Speeding</td>
<td>$250-$500</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>New Jersey</td>
<td>All moving vehicle violations</td>
<td>Double original fine</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>New Mexico</td>
<td>Speeding</td>
<td>Double original fine</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>New York</td>
<td>Speeding</td>
<td>$50-$500 or up to 30 days in jail, or both</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>North Carolina</td>
<td>Speeding</td>
<td>Additional $250 plus court costs</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>North Dakota</td>
<td>Speeding</td>
<td>Minimum $80</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Ohio</td>
<td>Speeding</td>
<td>Double original fine</td>
<td>Must be during hours of actual work</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Sources: Governors Highway Safety Association, September 2013
<table>
<thead>
<tr>
<th>State</th>
<th>Violations Affected</th>
<th>Enhanced Penalties</th>
<th>Workers Must Be Present</th>
<th>Signs Must Be Present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ohio</td>
<td>Speeding</td>
<td>Double original fine</td>
<td>Must be during hours of actual work</td>
<td>Yes</td>
</tr>
<tr>
<td>Oklahoma</td>
<td>Speeding</td>
<td>Double original fine</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Oregon</td>
<td>Various</td>
<td>Minimum: 20% of max. (misdemeanor), 2% of max. (felony)</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>Various</td>
<td>Double original fine</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Rhode Island</td>
<td>Speeding</td>
<td>Double original fine</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>South Carolina</td>
<td>Speeding</td>
<td>$75-$200 or up to 30 days jail, or both</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>South Dakota</td>
<td>Speeding</td>
<td>Double original fine (up to $500) or 30 days jail, or both</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Tennessee</td>
<td>Speeding</td>
<td>$250-$500</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Texas</td>
<td>All moving vehicle violations</td>
<td>Double original fine</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Utah</td>
<td>Speeding</td>
<td>Minimum double original fine</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Vermont</td>
<td>Speeding</td>
<td>Double original fine</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Virgin Islands</td>
<td>Speeding</td>
<td>No data</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Virginia</td>
<td>Speeding</td>
<td>Up to $500</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Washington</td>
<td>Speeding</td>
<td>Double original fine</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>West Virginia</td>
<td>Speeding</td>
<td>Up to $200 or 20 days in jail, or both</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>Various</td>
<td>Double original fine</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

| Total States | 49 + D.C., Virgin Islands | 24 + D.C. | 41 + D.C. |

Sources: Governors Highway Safety Association, September 2013
### Fines for speeding in Ontario work zones

<table>
<thead>
<tr>
<th>Km/h over posted speed limit</th>
<th>Fines for speeding in construction zones</th>
<th>Demerit points</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 km/h</td>
<td>$ 60</td>
<td>0 points</td>
</tr>
<tr>
<td>20 km/h</td>
<td>$ 180</td>
<td>3 points</td>
</tr>
<tr>
<td>30 km/h</td>
<td>$ 420</td>
<td>4 points</td>
</tr>
<tr>
<td>40 km/h</td>
<td>$ 560</td>
<td>4 points</td>
</tr>
<tr>
<td>50 km/h</td>
<td>$ 975</td>
<td>6 points</td>
</tr>
</tbody>
</table>

Sources: Ministry of Transportation, Ontario (http://www.mto.gov.on.ca/english/traveller/constructionzone.shtml)

### Fines for speeding in Quebec work zones

<table>
<thead>
<tr>
<th>Offence</th>
<th>Fines for offences</th>
<th>Fines</th>
</tr>
</thead>
<tbody>
<tr>
<td>If you exceed the speed limit by 1 to 20 km/h</td>
<td>$15, plus $10 for each additional 5 km/h over the speed limit</td>
<td>$15 to $55</td>
</tr>
<tr>
<td>If you exceed the speed limit by 21 to 30 km/h</td>
<td>$15, plus $15 for each additional 5 km/h over the speed limit</td>
<td>$75 to $105</td>
</tr>
<tr>
<td>If you exceed the speed limit by 31 to 45 km/h</td>
<td>$15, plus $20 for each additional 5 km/h over the speed limit</td>
<td>$135 to $195*</td>
</tr>
<tr>
<td>If you exceed the speed limit by 46 to 60 km/h</td>
<td>$15, plus $25 for each additional 5 km/h over the speed limit</td>
<td>$240 to $315*</td>
</tr>
<tr>
<td>If you exceed the speed limit by 61 km/h or over</td>
<td>$15, plus $30 for each additional 5 km/h over the speed limit</td>
<td>$375 or over*</td>
</tr>
<tr>
<td>Driving too fast for road or weather conditions</td>
<td>$60 to $100 fine</td>
<td></td>
</tr>
</tbody>
</table>

*Excessive speeding

Fines are doubled when drivers are convicted of an excessive speeding offence. Fines are tripled if drivers are convicted of an excessive speeding offence after three or more convictions for excessive speeding over the previous 10 years after this measure came into effect.

Speeding in a roadwork zone

Fines are doubled for speeding offences committed in roadwork zones. In the case of speeding offences, penalties for this type of offence apply.

### Fines for speeding in New York State Work Zones

<table>
<thead>
<tr>
<th>km/h Over Posted Speed Limit</th>
<th>Minimum Fine</th>
<th>Maximum Fine</th>
</tr>
</thead>
<tbody>
<tr>
<td>by 1.6 to 16</td>
<td>$45</td>
<td>$150</td>
</tr>
<tr>
<td>by 17.6 to 48</td>
<td>$90</td>
<td>$300</td>
</tr>
<tr>
<td>Over 48</td>
<td>$180</td>
<td>$600</td>
</tr>
</tbody>
</table>

Sources: New York Legislature, August 2012
(http://www.nytrafficticket.com/blog/index.php/2012/08/15/facts-about-speeding-in-a-work-zone/)